COEUR D’ALENE RIVER BASIN

Model Development Report for 1D Hydraulic Model Lower Basin of the Coeur d’Alene River (OU3)

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1.0 Introduction

The United States Environmental Protection Agency (EPA) is investigating environmental contamination and evaluating possible remedial actions for the Lower Basin of the Coeur d'Alene River (Operable Unit 3 [OU3]) in north Idaho (Exhibit 1). A set of four computer simulation models will be used as part of the evaluation process:

1. Hydrologic model representing flows from tributaries within the Lower Basin not accounted for by measured flow data on the North Fork and South Fork Coeur d'Alene rivers (Hydrological Engineering Centers Hydrologic Modeling System [HEC-HMS]).
2. One-dimensional (1D) hydraulic model covering the entire Lower Basin (Hydrological Engineering Centers River Analysis System [HEC-RAS], the focus of this report).
3. Two-dimensional (2D) hydraulic model covering the entire Lower Basin (MIKE 21C).
4. 2D sediment transport and morphology model covering the entire Lower Basin (MIKE 21C). This model is dynamically coupled with the 2D hydraulic model, but is described as a separate model since the hydraulic component can be applied separately.

A Modeling Work Plan (CH2M HILL, 2011) has been developed that describes each of the simulation models, how they are related, and how they will be developed and ultimately applied as decision support tools in the Lower Basin.

This technical memorandum describes the development of the 1D hydraulic model, one of the primary components of the simulation modeling set. Unless specifically indicated otherwise, the term "model" is used in this document to describe the 1D hydraulic model. The 1D hydraulic model simulates coarse-scale hydraulics; more complex hydraulics and sediment transport processes will be simulated separately using the 2D sediment transport model. The simulation model components are illustrated in Exhibit 2.

The 1D hydraulic model provides a coarse-scale description of channel–floodplain hydraulic interactions and facilitates coarse-scale testing and evaluation of the river and floodplain responses to potential remedial actions (such as changes in the location, frequency, and duration of floodplain inundation). The development of this model has provided valuable information on the relative importance of specific boundary inputs and uncertainties, and this information will help guide the development of the 2D hydraulic model. This model will also be used to guide future data collection efforts and enhance the overall understanding of the complex hydraulic interactions within Lower Basin river system functions.

More than a century of mining, milling, and smelting practices in the Coeur d'Alene River Basin have resulted in the release of large quantities of mine wastes that have been carried as sediment into the lower reaches of the Coeur d'Alene River, into Coeur d'Alene Lake, and beyond. This sediment contains concentrations of several metals that can be harmful to human and ecological receptors. Areas affected by these mining wastes were listed on the National Priorities List in 1983 as the Bunker Hill Mining and Metallurgical Complex Superfund Facility (EPA, 2001).

The lower 37 miles of the mainstem of the Coeur d'Alene River, from the confluence of the North Fork and South Fork to the mouth of the river at Coeur d'Alene Lake (see Exhibit 1), is commonly known as the Lower Basin. The Lower Basin consists of the sinuous channel of the lower Coeur d'Alene River and numerous hydraulically interconnected marshes and lakes. Contaminated sediment has been deposited throughout the river bed and banks of the river, and the adjacent lakes, marshes, and floodplains of the Lower Basin.

A remedial investigation and a feasibility study were prepared for the entire Coeur d'Alene River Basin in 2001 (EPA, 2001), and an Interim Record of Decision (Interim ROD) was issued in 2002 (EPA, 2002). The Interim ROD defined 30 years of prioritized cleanup actions, while recognizing that additional actions were needed to protect human health and the environment. EPA has continued data collection and evaluation of the nature, extent, transport, and fate of contamination in the Lower Basin, and recently summarized the current understanding, and remaining data gaps, in an Enhanced Conceptual Site Model (ECSM) (CH2M HILL, 2010a). The ECSM specifically addressed modeling and data needs, and these are addressed in greater detail in the Modeling Work Plan (CH2M HILL, 2011). Evaluations of remedial actions will be based on the supplemental data, modeling outputs, and enhanced understanding of the river system.

Development of effective remediation strategies for the Lower Basin will require an understanding of the hydraulic interactions among the river, lakes, marshes, and floodplains during a wide range of flow conditions. In particular, there is the need to understand the frequency, duration, and spatial extent of floodplain inundation. Computer models describing water and sediment flow in the Lower Basin will help enhance understanding of the sources, pathways, and depositional areas for contaminated sediments. These models are based on mathematical equations that represent physical processes. Model scenarios (representing a range of river flows and water elevations, sediment loading levels, and modifications to the river channel and banks) can be set up to evaluate and compare the resulting flow velocities, shear forces, sediment transport, erosion and deposition patterns, and other factors. Comparison of the model predictions for different potential actions will be used to assess the options for pilot studies and remedial actions, and to evaluate and improve upon the expected effectiveness and design characteristics of potential remedial actions.

The spatial scope of the 1D hydraulic model includes the entire Lower Coeur d'Alene River from the confluence of the North Fork and South Fork to its outlet at Coeur d'Alene Lake. For the model development phase, the temporal scale will focus on the period between 2010 and 2012, the period for which calibration and validation data exist. Once developed, the temporal scale for the model will be expanded to include historical runoff events for which flow data exists at the North Fork and South Fork gages, from August 1987 to present.

1.1 Purpose

This document describes model development procedures including data sources, boundary condition setup, model parameterization, and calibration and validation methods and results. Following successful calibration, the model will be used to characterize the existing river system, to support development of the 2D model, and ultimately to evaluate remedial action options. Future model applications will be documented separately.

1.2 Document Organization

The main text of this document provides a description of the 1D modeling approach, calibration results, validation results, and discussion, with detailed technical information provided in the attachments and exhibits. This document is organized into the following sections:

- **Section 1.0, Introduction.** Establishes the purpose, scope, context, and content of this technical memorandum.

- **Section 2.0, Background. D**escribes the project area, contaminants of concern and the application of modeling to them, and previous modeling conducted for the Lower Basin.
- **Section 3.0, Modeling Approach.** Introduces modeling software that was used for the 1D hydraulic model.
- **Section 4.0, Model Development.** Outlines the types of data and model network elements that compose the 1D hydraulic model and discusses the specific features of the Lower Basin as they are represented in the model. Also discusses model stability issues and the format of modeling output.
- **Section 5.0, Calibration and Validation.** Identifies available data and describes the calibration and validation processes and sensitivity analysis. Provides a summary assessment of the model's reliability.
- **Section 6.0, Assumptions, Limitations, and Uncertainty**. Qualifies interpretation of the modeling results in terms of the limits of the modeling software platform, data availability, and other factors.
- **Section 7.0, Future Model Applications**. Explains how the 1D hydraulic model will be used to further refine the conceptual site model, support data collection and interpretation, evaluate remedial action alternatives, and guide design of remedial and restoration actions.
- **Section 8.0, Conclusions.** Presents overall conclusions about the 1D hydraulic model and its results.
- **Exhibits 1 through 52.** Tables and Figures that support understanding of the model and its results. A full list of exhibits is included at the beginning of the Exhibits section.

Additional technical detail supporting Sections 4.0 and 5.0 is included in three attachments:

- **Attachment A.** Glossary
- **Attachment B.** U.S. Geological Survey (USGS) Flow and Stage Data Processing
- **Attachment C.** Electronic files of HEC-RAS Model, including Boundary Conditions and Level Logger Data

2.0 Background

The Lower Basin of the Coeur d'Alene River extends about 37 miles from the confluence of the North Fork and South Fork of the Coeur d'Alene River to Coeur d'Alene Lake. About 29 miles of the Lower Basin is relatively flat gradient in a sinuous channel. The river is hydraulically connected to numerous shallow lakes and marshes through a series of natural and manmade channels and flow pathways. During high water, the river overtops its banks and enters the floodplain; in major floods, much of the river valley is inundated. More than a century of human activity in the region has influenced the physical and environmental characteristics of the Lower Basin, including direct discharges of mining wastes in upstream tributaries, the construction of the Post Falls Dam on the outlet of Coeur d'Alene Lake, the construction of a rail line (and embankment) up through the Lower Basin, construction of dikes and dredging of connection channels along the river and in off-channel areas, and dredging the river bed in the Cataldo area. A significant amount of investigative work has been conducted over the past several decades to document the physical and environmental characteristics of the Lower Basin, including the remedial investigation (EPA, 2002). Further investigations and modeling efforts were conducted after the remedial investigation; the status of site parameters was updated and summarized in the ECSM (CH2M HILL, 2010a). The ECSM provides focused examination of available data and findings related to relevant topics in a series of technical memorandums, including hydrology, hydraulics and sediment transport, geomorphology, contaminant characteristics, and data gaps.

Based on the understanding of the Lower Basin documented in the ECSM, the Modeling Work Plan (CH2M HILL, 2011) was developed to describe the approach to developing and applying simulation modeling tools. The Modeling Work Plan describes the general strategy of sequentially developing 1D, 2D, and sediment transport models; the process planned for model parameterization, calibration, and validation; the intended uses of the models to help evaluate remedial action options; and the documentation planned for each model. The Modeling Work Plan also provides a summary of the physical setting of the Lower Basin and a brief description of previous modeling efforts of the river.

In addition to gaged input flows of the North Fork and South Fork tributaries, the 1D hydrodynamic model also uses hydrologic modeled flow of minor tributaries discharging into the Lower Basin, which are estimated by net gaged flow records to represent about 10 percent of the flow entering the upstream boundary of the basin. This hydrologic model, the U.S. Army Corp of Engineer's (USACE) HEC-HMS, is discussed in more detail in Section 4.5, and is fully documented in the Modeling Work Plan (CH2M HILL 2011).

3.0 Modeling Approach

One-dimensional hydraulic models perform 1D hydraulic calculations for steady and unsteady (changing with time) gradually varied flow in open channels. For the Lower Basin model, only unsteady flow simulations will be performed since steady state simulations are not capable of accounting for the effects caused by storage areas (i.e., flow attenuation), which are abundant in the Lower Basin. The hydraulic calculations used by the model are based on the principles of conservation of mass and momentum that govern the flow of water and are expressed mathematically as partial differential equations. More information on the equations and numerical methods used by the model can be found in the software's hydraulic reference manual (USACE, 2010a).

The modeling software being used is HEC-RAS version 4.1 (January 2010) developed by the USACE. HEC-RAS is public domain software that can be downloaded, along with supporting documentation, from the HEC-RAS website (http://www.hec.usace.army.mil/software/hec-ras/). More information about model selection can be found in the *ECSM Technical Memorandum H – Model Evaluation and Recommendation* (CH2M HILL, August 2010).

Two additional software tools created by USACE were used to assist with model development and results evaluation: HEC-GeoRAS version 4.2.93 and HEC-DSSVue version 2.0.1. HEC-GeoRAS is a geographical information system (GIS) software extension (extension to ArcGIS) used to develop model geometry within a geospatial context. HEC-GeoRAS uses digital terrain model (DTM) elevation data to develop input files for HEC-RAS. HEC-DSSVue is a tool used for quickly graphing, editing, and manipulating large time-series datasets. This tool uses the HEC Data Storage System (DSS) database that is common to many USACE software systems.

One of the primary challenges associated with applying a 1D model is in setting up the model to replicate 2D processes with a series of 1D tools. When rivers rise and overtop their banks, water flows outward inundating the floodplain and filling storage areas, and the process is reversed as water levels recede. This is an inherently 2D process that requires careful consideration when developing a modeling approach. The approach used for the Lower Basin 1D model is to model the main channel with cross sections that exchange water with the floodplain using lateral structures connected to storage areas. The floodplains, which are composed largely of lakes, marshes, and wetlands, are modeled as distinct storage areas and each storage area tracks changes in water surface elevation based on inflows and outflows from its adjacent connections (the main channel or other storage areas). This is a commonly used approach, which is quite effective when reliable survey data are available and the channel-floodplain connectivity is well defined. Exhibit 3 shows a diagram of the quasi-2D model setup being used in HEC-RAS. How well this approach works for the Lower Basin model is reflected in the quality of the calibration, which is described in Section 5.0. The limitations associated with the Lower Basin 1D model are described in Section 6.

4.0 Model Development

Model development consists of laying out the model network that defines the physical connectivity of the river system and assigning the associated geometry to each network element. In the case of the model for the Lower Basin of the Coeur d'Alene River, the model network consists of a model centerline divided into model reaches, cross sections that provide the primary channel geometry and define channel roughness, storage areas that represent lateral lakes, and a series of hydraulic controls (storage area connections, lateral structures, culverts, bridges, and pumps) that allow bidirectional flow from the channel to the lateral lakes. Once the model network has been established, the model requires boundary conditions, which consist of all inflows to the model and a water level boundary at the outlet of the model, Lake Coeur d'Alene in this case. The details of the model network and its boundary conditions are described in the following sections.

4.1 Units and Datums

Metric units are used in the model. Exhibit 4 lists typical units and their application within the model. Some results are presented in both metric and imperial units to aid in understanding. Unless otherwise noted, all elevations are referenced to the North American Vertical Datum of 1988 (NAVD 88)[1]. Horizontal position is referenced to the North American Datum 1983 Universal Transverse Mercator Zone 11 North.

4.2 Model Domain Boundary

The HEC-RAS model simulates the hydraulics of the Coeur d'Alene River and associated floodplain within the Lower Basin. The model extends longitudinally from an interface with Coeur d'Alene Lake 50 meters downstream of Highway 97, near the town of Harrison, at River Mile 132.7, to a point on the North Fork just upstream of the confluence at River Mile 168.4, 0.6-miles downstream of the Enaville USGS stream gage, and to a point on the South Fork just upstream of the confluence at River Mile 168.3, 1.1-miles downstream of the Pinehurst USGS stream gage. It extends laterally across the low-lying floodplain and includes numerous lateral lakes that are directly and indirectly connected to the river. The model domain boundary is shown in Exhibit 1.

4.3 Survey Data

Many elements of the model network are developed from a DTM that was in turn developed from a collection of survey data. Exhibit 5 lists the various data sources used to develop the DTM.

4.4 Model Network

Laying out the model networks consists of defining the spatial limits of each network element. Elements of the model network that define the river's connectivity include modeling reaches, cross sections, lateral structures, storage areas, culverts, and bridges. The model network for the Lower Basin is shown in Exhibit 6. The modeler uses aerial imagery, the digital terrain model, and professional judgment to determine the location, extent, and connectivity of each element. The following sections describe the model elements, how they were defined, and what input parameters are required. Refer to Exhibit 6 to see the spatial layout of the model elements.

4.4.1 Modeling Reaches

The river was divided into seven 1D modeling reaches[2] for the purpose of 1D model construction. These 1D model reaches define the location of many of the model elements, make it easier to view model inputs and outputs, and enable the user to quickly navigate to specific sections of the river. The reach delineations do not affect the model's computations; they are only used as an organizational tool. The names, locations, and extents of the modeling reaches are summarized in Exhibit 7 and Exhibit 15. The model reaches are different from the geographical river reaches, which are artificial boundaries that have been used throughout the Lower Basin project work to refer to distinct portions of the river. There are four geographical river reaches: Springston, Killarney, Dudley, and Braided, which are frequently referenced in the Enhanced Conceptual Site Model and other EPA documents.

4.4.2 Cross Sections

Cross sections define the flow carrying capacity of the river. They define the representative shape of the channel in a uniform reach and are placed strategically in locations where changes in discharge, slope, shape, or roughness

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[1] Multiple vertical datums have historically been used in the Coeur d'Alene River Basin, including NAVD 88, the National Geodetic Survey Datum of 1929 (NGVD 29), and the Avista Datum (also called Washington Water Power datum). The National Geodetic Survey's VERTCON (https://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl) is used for point conversions between NGVD 29 and NAVD 88, the conversion of which varies across the basin. The difference between NGVD 29 and NAVD 88 at the USGS gages in the Lower Basin range from 1.11 m to 1.17 m (Berenbrock and Tranmer, 2008). The lake gage at Coeur d'Alene has a difference of 0.24 m. The Avista datum is 0.930 m lower than NGVD 29 at Post Falls Dam (Black, 2003).

[2] Three different types of "reaches" are used and described in this model: geographic reaches (4), modeling reaches (7), and calibration reaches (11). All three sets of reaches are shown on Exhibit 15. Geographic reaches define geographically unique and separate areas and are used in many of the other ECSM documents. Modeling and calibration reaches are unique to the 1D model, and are used to define location of model elements (modeling reach) and to define the portion of river affected by calibration to a given gage location (calibration reach).

occur, and placed immediately upstream and downstream of hydraulic structures (for example, bridges and culverts). In general, cross sections are oriented perpendicular to the river banks and span only the main channel. Flow above the bank, or trail embankment, is routed to the adjacent floodplain using a weir connected to a storage area, which defines most floodplain areas. However, in select areas the floodplain is included in the cross section. Floodplains are included in the cross section where overbank flow parallels the river and the floodplain appears to have active conveyance and thus contributes to energy losses. These locations are primarily found in the three Braided Modeling Reaches and at narrow sections of floodplain that exist in the Meander Modeling Reach. Professional judgment was used to identify these areas through inspection of aerial imagery and the DTM for evidence of overland flow in the floodplain.

Ineffective flow areas are used to exclude portions of a cross section that do not actively convey flow. These areas are typically either lateral separation zones (eddies), or low-lying areas that do not actively convey flow until water crests the surrounding higher ground. Eddies commonly form in the floodplain upstream and downstream of bridges where the roadway embankment blocks a portion of the floodplain. These areas were delineated in the Lower Basin using a 1:1 flow contraction ratio upstream of the bridge and a 1.5:1 expansion ratio on the downstream side of the bridge. Low-lying areas were identified through close examination of the DTM when laying out the cross sections.

The cross sections are identified by their longitudinal position along the river, in meters. The cross section ID, or river station, defines the location of a given cross section relative to another, as well as defining the position lateral structures and bridges relative to the cross sections.

The model contains 730 cross sections, with the spacing selected to be equal to or less than the channel width. Locations of cross sections were also influenced by changes in channel geometry and/or changes in flow paths. Twenty-six of the cross sections are interpolated cross sections that were inserted to help with model stability. The average spacing is 88 meters (m). All the cross sections are shown on Exhibit 6. Cross sections have two primary attributes—geometry and roughness—which are discussed below.

Geometry. Cross section geometry was developed using an ArcGIS extension known as HEC-GeoRAS. Two-dimensional cross section lines were drawn in ArcGIS and transformed into three-dimensional (3D) lines by draping the 2D line over the 3D DTM. The 3D cross section lines were then exported from ArcGIS to HEC-RAS using HEC-GeoRAS. The cross section geometry attributes are stored as a series of paired values, where elevation is paired with distance (station) along the cross section line.

Roughness. Water flowing in a riverine environment experiences two forms of flow resistance: form drag and skin friction. Both of these affect hydraulic conditions (such as water level, velocity, and shear stress) and the energy that is available to transport sediment. Vegetation, planform geometry, bedforms, bed and bank particle sizes, and flow rate all contribute to flow resistance. In HEC-RAS flow resistance is accounted for through use of a Manning's n roughness coefficient that accounts for the combined resistance of form drag and skin friction. HEC-RAS uses a constant user-defined Manning's n coefficient in its formulation in the momentum equation; it does not vary as a function of stage or flow. The friction slope term is a function of both stage and flow but the Manning's roughness coefficient is not. To better account for stage-dependant flow resistance, HEC-RAS has an optional function that allows the user to scale roughness coefficients as a function of the local flow rate. The methodology used to assign Manning's roughness coefficients (n-values) in the model is described below, and the methodology used to develop the flow roughness scaling factors is described in Section 5.4.1, Roughness Calibration. Because the flow roughness development described below was used for the 1D and the 2D model, it was completed at the level of detail necessary for the 2D model—a level of detail that is much higher than that traditionally used for 1D modeling. Adjustments made during calibration were made at a more typical scale for a 1D model (that is, reach scale).

Roughness coefficients are only assigned to the cross sections (not storage areas), which in the Lower Basin model are limited to the main channel and small portions of the floodplain. Flow resistance through lateral lakes, marshes, and wetlands is not accounted for in this model (see Assumptions, Limitations, and Uncertainty Section for a description of the implications). Roughness coefficients were assigned spatially using maps developed in ArcGIS and applied to the model using HEC-GeoRAS.

Roughness maps for the channel and floodplain were developed separately and then merged together before being exported to the hydraulic model, with the intention that they would provide the inputs to both the 1D and 2D model. The boundaries of the roughness map encompass the entire Lower Basin, which in many areas are beyond the limits of the 1D cross sections.

Flow resistance in the main channel is affected mostly by bed form geometry and to a lesser extent, plan form drag and grain roughness. Manning's n roughness coefficients for the main channel were developed using the Strickler equation to relate roughness height (k_s) to Manning's roughness coefficient (n). The total roughness height was defined as the sum of the bed form roughness height and the grain roughness height (van Rijn, 1984).

Total roughness height (k_s):

$$k_s = k_s^{'} + k_s^{''}$$

where:

$$\text{grain roughness height,} \quad k_s^{'} = d_{90}$$

$$\text{bed form roughness height,} \quad k_s^{''} = 1.1\Delta\left(1 - e^{-25\zeta}\right)$$

$$\text{bed form steepness,} \quad \zeta = \frac{\Delta}{\Lambda}$$

$$\Lambda = \text{dune length}$$

$$\Delta = \text{dune height}$$

Total roughness heights were related to Manning's roughness coefficients using the Strickler equation:

$$n = \frac{k_s^{1/6}}{20}$$

Bed form units were spatially defined in ArcGIS by partitioning the bed based on the geometry and texture of the bed as interpreted from the multi-beam bathymetric data collected in 2011. Units were generally classified as plane bed, dunes, or rough. Bed form dimensions at a given location were defined based on local bed form geometry. Elevation profiles were extracted from the terrain model for each unit; bed form heights and lengths were measured manually and bed roughness height was calculated and assigned to respective bed form units.

Grain roughness heights were also assigned spatially in ArcGIS. Particle size data came from surface sediment samples collected with a petite Ponar sampler in 2010 and 2011. Three samples were taken across the channel (left, center, and right) at each transect, which were spaced between 0.25 mile and 0.5 mile apart in the Meander Modeling Reach. In the three Braided Modeling Reaches, Wolman pebble counts were collected at 16 exposed point bars. Particle size data were assigned to each bed form unit equal to the nearest sediment sample collected in the same bed form type (plane bed, dunes, or rough bed).

The computed roughness parameters and associated Manning's roughness coefficients are shown in Exhibit 8.

Roughness in the floodplain was assigned using mapped surficial geology, wetlands, and deep water habitats from Bookstrom and others (1999). Bookstrom delineated unique vegetated areas and assigned subclassification fields based on the Cowardin wetland classification system (Cowardin and others, 1979). Each subclass was assigned a typical vegetation roughness using guidance from the USGS (1990) and the HEC-RAS Reference Manual (Table 3-1, USACE, 2010a, based on Chow, 1959). Because the floodplain vegetative roughness can vary by season, a summer and winter roughness value was selected. The winter value was used in the Lower Basin model because most of the flooding of interest occurs in the winter and spring when vegetation is in a dormant state. Summer roughness values can be substituted in the model as necessary; however, only one set of roughness values can be included in the model for a given simulation. Exhibit 9 lists the Cowardin subclass names used for vegetation delineation by Bookstrom associated with the winter and summer roughness values used in Lower Basin model.

The combined floodplain and channel roughness coefficients are mapped in Exhibit 8. The roughness coefficients used in the model were further adjusted during model calibration, which is described in Section 5.4.1, Roughness Calibration.

4.4.3 Storage Areas

Storage areas are used to represent the lateral lakes, wetlands, and marshes. Storage areas track the water surface elevation in the off-channel areas in response to the flow volume exchange between connected features such as the main channel and adjacent interconnected floodplains. Flow between connecting features is exchanged using a standard weir equation and the headwater and tailwater elevations of respective features. The model does not account for flow resistance in the areas defined with storage areas; areas with considerable active conveyance should be modeled using cross sections, where practical. Changes in water surface elevation within a storage area operate along the unique stage-storage curve defined for each lake, marsh, wetland, and floodplain. Each stage-storage curve was calculated from the DTM using HEC-GeoRAS software; stage-storage curves can be viewed within the HEC-RAS model (electronic Attachment C). Storage areas are connected to the river via lateral structure connections and connected to other storage areas via storage area connections. Both of these features are discussed in detail in the following sections.

The Lower Basin model has 36 storage areas. Their names, identification numbers, and locations are shown on Exhibit 6; their connections to the river and other storage areas are summarized in Exhibit 10.

4.4.4 Storage Area Connections

Storage area connections are used to define the exchange between adjacent storage areas. The model uses a weir equation to calculate the flow exchange between two storage areas using their respective headwater and tailwater conditions. These are used in the Lower Basin where a feature cuts through a lake or marsh and impedes the free flow of water, causing a head differential and controlling the flow exchange between the two water bodies. For example, a storage area connection is used to define the trail embankment that divides Lane Marsh—flow between Lane Marsh north and Lane Marsh south can either flow over the trail embankment as weir flow, or through the bridge opening.

The model contains 21 storage area connections. Their identification numbers and locations are shown on Exhibit 6, and the storage areas they connect are listed in Exhibit 11 with culvert information.

4.4.5 Lateral Structures

Lateral structures are model elements that allow model flow to leave the channel laterally and flow into the floodplain and come back into the channel as water levels recede. This enables the 1D model to represent a fundamental 2D process that occurs in most river systems.

Accurately defining the location, geometry, and connectivity of the lateral structures is critical to setting up the model to successfully replicate the lateral exchange process between the river and its floodplain. These structures are located on the crest (high point) of the bank or levee that controls the flow exchange between the two water bodies. To develop the model, the structure alignments were defined in GIS through careful examination of the DTM. The geometry data (station-elevation) were extracted from the DTM and transferred to the hydraulic model using HEC-GeoRAS software. To calculate the flow exchange across the structure, the model uses a basic weir equation to calculate the flow exchange based on the head differential. In addition to the weir's geometry, the model requires a discharge coefficient.

Culverts were added where their presence was known. Most of the culverts primarily serve to drain the off-channel areas. They have little effect on mainstem hydraulics during flood conditions, but without these features the model would not be able to simulate consecutive floods because some of the storage areas would not drain.

The model contains 42 lateral structures. Their identification numbers and locations are shown on Exhibit 6, and their connectivity is summarized in Exhibit 12.

4.4.6 Hydraulic Structures

Culverts. Culverts allow flow to pass through roadway and trail embankments and other flow barriers. In the Lower Basin model, they allow flow between lateral lakes (storage areas) and between the river and adjacent lateral lakes. Flow through a culvert is calculated from the difference in water surface elevation between the upstream and downstream end of the culvert using standard culvert equations. The geometry of a culvert is defined by its length, upstream invert elevation, downstream invert elevation, diameter, and shape. Flow resistance through the culvert is accounted for using the Manning's roughness coefficient. Specific values were assigned based on the assumed culvert material.

Culvert locations and geometry were obtained from a combination of sources, including field survey data, as-built drawings, field photos, aerial imagery, and other anecdotal evidence. In general, the culverts convey very little flow relative to the total river flow. Their primary function is to provide drainage in areas where water is trapped behind embankments, which is critical for obtaining the correct water level in floodplain areas after a flood event so that the storage volume available for subsequent floods is correct.

The model contains 13 culverts. They are located on lateral structures and storage area connections that are shown on Exhibit 6 and their geometry is summarized in Exhibit 13.

Bridges. Bridges across the main stem of the Coeur d'Alene River and the North Fork are explicitly included in the model. The presence of a bridge abutment, deck, and piers reduces the available flow conveyance area and introduces contraction and expansion losses that affect the hydraulics of the river. Bridge deck elevation and width was determined from LiDAR and aerial imagery. Remaining parts of the bridge geometry, such as bridge deck depth; number, placement, and size of piers; and abutment geometry were estimated from photos taken during a floating reconnaissance of the river in October 2009. The file name of the photo used to estimate bridge geometry is recorded in the description field of the bridge. The *Average Conveyance* friction slope method is used for bridge flow calculations. This is the default method in the HEC-RAS modeling environment. The *Energy* method is used for the bridge modeling approach.

Bridges formed by the Trail of the Coeur d'Alenes across tie channels connecting lateral lakes and the river were not explicitly included in the model. HEC-RAS is unable to simulate bridges that are parallel to the river and perpendicular to cross sections, as the tie channel bridges would be. The connection representing the tie channel is included in the model as part of the geometry of the lateral structure or storage area connection through which the tie channel flows. This geometry was developed from the DTM and was surveyed in the field. Because a bridge is not explicitly modeled across the tie channels, entrance losses, exit losses, and losses resulting from overtopping and pressure flow are not included in the model calculations.

The model contains nine bridges. Their locations are shown on Exhibit 6 and their connectivity is summarized in Exhibit 14.

Pump Stations. The Lower Basin has several small pump stations that serve to drain flood waters that become trapped behind levees when river levels recede. The size and operation of most pump stations is not known and these small pump stations are not included in the model. To simulate the draining of water trapped behind levees, small culverts have been added to the model to allow flood waters to slowly return to the river, similar to the behavior of a small pump. One larger pump station is included in the Lower Basin geometry, located at Fourth of July Creek (Pump ID FOJC_PS). This pump station is set to pump water from Storage Area 1249-CanyonMarsh to Meander Modeling Reach RS = 38453.50, based on the water surface elevation in the Canyon Marsh storage area. The model pump station is meant to approximately replicate a series of pumps observed in the field that serve to pump flows from Fourth of July Creek over a levee to keep low-lying fields dry at opportune times of the year. Actual pump operations are variable to meet land owner needs and optimize conservation of energy. Ten modeled pumps step up flow rates in increments of 2 cubic meters per second (cms), up to 20 cms, which is greater than the peak 3-day average flow rate from the 2009-2011 HEC-HMS model run of 19.28 cms.

4.5 Boundary and Initial Conditions

The Lower Basin is conveniently bounded by USGS flow and stage gages at its upstream and downstream boundaries. The model boundaries have been aligned with these gages so that historical flow and water level data can be used to define the model's boundary conditions. The two upstream boundaries are defined by flow recorded at gages on the North Fork at Enaville (USGS gage 12413000) and the South Fork at Pinehurst (USGS gage 12413470). The downstream boundary condition is defined by water surface elevations recorded at the mouth of the Coeur d'Alene River near Harrison, just downstream of Highway 97. The water surface elevations used to define the downstream boundary were modified slightly from the recorded values, since the model boundary is located a short distance downstream of the gage. Flows from tributaries within the Lower Basin are included as lateral inflow hydrographs at multiple locations throughout the model. Water from these Lower Basin tributaries flows into storage areas and in some cases directly into the river. The locations of all the boundary conditions are shown in Exhibit 15 and summarized in Exhibit 17.

Flow hydrographs at the North Fork and South Fork are developed from USGS gage data. Fifteen-minute data are available for much of the period of record. For periods where 15-minute data are not available, mean daily flow data are used (when available) to interpolate between missing 15-minute data. Limited periods where both 15-minute and mean daily flow data are missing were filled by interpolating between known data points. Some flow data for 2013 are classified as provisional by the USGS at the time of the writing of this report.

Numerous ungaged tributary flows enter the river between the confluence and mouth. Flows from these tributaries were generated using a HEC-HMS hydrologic model. The development, calibration, and results of the hydrologic model are discussed in detail in the Hydrologic Model Technical Memorandum (CH2M HILL, 2013). Modification of the tributary flows is discussed in Section 5.3, Flow Calibration.

Locations of model flow inputs are shown in Exhibit 18. Hydrographs of all the flows shown as inputs in Exhibit 18 are shown in Exhibit 19. Exhibit 19 is ordered from downstream to upstream and is organized by geographic reach.

Stage (and therefore water surface elevation) data are recorded by the USGS near the mouth of the Coeur d'Alene River (Gage 12413860, COEUR D ALENE RIVER NR HARRISON ID). These data are recorded at the Springston Bridge, which is approximately 2,960 m upstream of the downstream model boundary at Highway 97. Because of energy losses between the Harrison Gage and the downstream boundary, the water surface elevation measured at the Harrison Gage does not accurately represent conditions at the boundary and is only used as an initial estimate of the boundary water surface elevation. Because the energy losses along the downstream-most 2,960 m of the model vary, the model is used to estimate energy loss between the Harrison Gage and the downstream boundary condition. The difference in modeled water surface elevation between these two points is subtracted from the measured stage at the Springston Bridge, and the result is used as an updated boundary condition. The model is then re-run with this updated boundary condition. This process was iterated until the greatest difference in boundary condition elevation between successive runs was less than 0.01 m, and the mean difference in boundary condition elevation was less than 0.00001 m. Exhibit 20a shows the difference between the Harrison Gage and the downstream model boundary.

Data at the Harrison Gage is only available from March 1, 2004, to the present. Model simulations before 2004 will need to develop a downstream boundary condition using data recorded at the Lake Coeur d'Alene gage (USGS gage 12415500) [Lake Gage] located near the City of Coeur d'Alene, which has a longer period of record (1904 to present). Water surface elevations recorded at the Lake Gage do not correlate well with water surface elevations at Harrison during flood conditions. Model scenarios that use data, or adjusted data, from the Lake Gage would have a higher degree of uncertainty associated with the downstream boundary condition; this is discussed further in Section 6. The difference in water surface elevation between the Harrison and Coeur d'Alene gages is shown in Exhibit 20b.

A detailed description of methods used to process USGS flow and stage data, as well as a detailed list of missing and interpolated date ranges, is included in Attachment B. Electronic files of the boundary conditions are included in DSS files in Attachment C.

Model stability is sensitive to initial conditions of the lateral lakes and river. The initial conditions used for model calibration were developed iteratively. Once the model was stabilized, October 2010 model results from a longer simulation starting in 2004 were used to set the calibration initial conditions for model calibration runs. When applying the model to other time periods, unique initial condition files are needed. Initial conditions files have been created for water year (WY) 2005 through WY 2012. The initial conditions are listed in Exhibit 21.

4.6 Model Stability and Debugging

Numerous model elements affect model stability. The process of iteratively revising individual model elements to improve stability is called *debugging*. In this procedure, the model is run using HEC-RAS unsteady flow equations. At each computational time step, and at each model cross section, the continuity equation and momentum equation are iteratively and simultaneously solved (USACE, 2010a). These two equations can fail to converge on a solution for many different reasons (of which some of the more common ones are briefly described here) and can cause what is generally known as *model instability*. A model is considered stable when these two equations can be solved within an acceptable number of iterations and converge within an acceptable difference in water surface elevation. The acceptable number of iterations and difference in water surface elevation is set by the modeler, conforming to general modeling standards. Model stability tolerances were set as listed in Exhibit 22.

If the model is unable to solve the required equations within the tolerances set above, it ceases to run. Even if the model does complete a run, it may do so with errors, which are recorded in a run output file. The modeler reviews this file and evaluates if the errors listed are acceptable.

Common sources of Lower Basin HEC-RAS model instability involve issues related to the modeled channel "drying out" during low flow, water surface elevations changing rapidly (such as during a flash flood event), poorly defined initial conditions, and run parameters (such as computational time step). Changes made to the model during the debugging process are listed as follows; sensitivity and uncertainty analysis related to these model changes are presented in the Sensitivity Analysis and Uncertainty sections and are summarized in Exhibit 51.

- Braided Modeling Reaches Geometry
  - Added interpolated cross sections in the Braided Modeling Reach where the longitudinal profile is relatively steep.
  - Added pilot channel to Braided North Modeling Reach to allow for low flows to pass without channel drying out. Pilot channel geometry (depth and width) is insignificant compared to overall cross section and won't affect hydraulics at higher flows.
  - Added a minimum flow for North Fork Modeling Reach (7.45 cms) and South Fork Modeling Reach (3.17 cms); instability issues are greatest at low flows. Flows below these minimum flows occur less than 15 percent of the time. Periods during which these minimum flows are used in lieu of gaged flows are indicated on Exhibit 19.e.
- Storage Areas
  - Because model stability is highly sensitive to the initial conditions (water surface elevations) in storage areas, performed multiple iterations to identify the initial conditions that were stable.
  - Lowered the minimum elevation at some storage areas; raised the maximum elevation at some storage areas.
  - Revised storage-elevation curve to increase minimum volume step (for example, instead of using 0.00 to 0.01 at the lowest end).
- Time Step
  - Ran the model over a wide range of time steps to test the model's sensitivity and stability response to the time step. While the model will run with a time step of 3 minutes, or greater for some time periods, a time step of 1 minute was found to produce the fewest instabilities. Model run times with a time step of

1 minute are about 3 hours for simulating a full water year; run times vary slightly depending on the individual computer specifications.

- Blessing Slough
  - Added ineffective flow areas, a road modeled as a bridge with a culvert, and defined a minimum flow of 3 cms.
- Fourth of July Creek Pump Station
  - Determined settings, number of pumps, and on/off times.
- Flow split junctions
  - Made junction distance positive; initial default value was set to zero.

Even with the debugging activities described previously, minor model instabilities remain at some storage area connections and lateral structures. These instabilities are characterized by small rapid fluctuations in flow into and out of a storage area. These fluctuations typically occur on the order of 0.05 to 0.5 cms over durations of a few minutes to a few hours, and result from complications of calculating flow over multiple complex weirs (up to five) into and out of a single storage area. Because these rapid fluctuations are relatively small and occur during short time periods, the net volume associated with these fluctuations has a negligible effect on water levels in the storage areas and thus doesn't pose a concern from a model accuracy and reliability perspective.

4.7 Model Outputs

HEC-RAS generates a long list of parameters at each model element (cross section, storage area, lateral structure, storage area connection, and pump station) at each time step specified in the Unsteady Flow Analysis Plan. The parameters most commonly used for analysis of the Lower Basin model results are listed in Exhibit 23.

Model results can be viewed directly in HEC-RAS, as well as in the HEC-DSSVue database program. Results in both of these file systems can be viewed graphically and in table form. Each format presents unique strengths for viewing and understanding model results. HEC-RAS allows for quick graphic display, links related elements (such as storage areas with storage area connection and lateral structures with river cross sections), has preset viewing windows (such as that for viewing water surface elevation, flow, and velocity profiles), and can animate results over time. HEC-DSSVue allows for relatively easy manipulation of results, including statistical analysis and performing mathematical operations. It also allows for quick comparison of time-series data from multiple model elements.

5.0 Calibration and Validation

Model calibration is the iterative process of adjusting model parameters so that simulated results match observed results sufficiently. Calibration is part of the parameterization process, wherein some of the available data (such as water levels) may be used to guide adjustment of one or more of the model input parameters (such as roughness coefficients). The accuracy of a model's calibration is a key measure of its reliability. This provides a critical piece of information when using model results to inform decision making.

Model calibration is a function of the quality of data inputs, model parameterization, and complexity and scale of the processes being modeled. The quality of calibration and subsequent results may be limited by poor parameterization and by data that are inadequate, outdated, of poor resolution, or are missing or assumed.

Model validation uses data that have not been used as part of calibration to test the accuracy and reliability of the model in predicting known outputs. The validation process is intended to demonstrate that the changes made during the calibration process are applicable to other flood events. An accurate validation helps provide confidence in the model's ability to simulate flood events other than the ones used during calibration and that the changes made during calibration are universally applicable. Model validation is considered successful if the residuals from the validation run are of similar magnitude, timing, and frequency compared to those from the final model calibration. If the model does not perform well during validation, additional data collection and calibration may be required to gain the necessary confidence in the model output.

This section begins with an outline of the calibration process and a review of the data that are available for calibration and validation. This is followed by a description of the flow and water surface elevation calibrations that were performed and their results. Then, the validation process and sensitivity analysis are discussed. Finally, on the basis of the calibration and validation results and the sensitivity analysis, the reliability of the model is assessed.

5.1 Calibration Process

The calibration process involves a series of iterative model adjustments that progressively improve the model accuracy. The process begins with the adjustments that have the biggest effect on model results and progresses toward those that have smaller effects. And, because changes to the model at one location, or to one parameter, have ripple effects throughout the model, it is necessary to make adjustments iteratively and evaluate the effects of adjustments throughout the model domain. The calibration process is described according to its two calibration metrics: flow and water surface elevation.

1. *Flow Calibration*—Compared the model-predicted flows at the downstream end of the model (cross section 2972.734, at the Springston Bridge near the town of Harrison), to those measured by the USGS gage (Gage 12413860, at the Springston Bridge). Flow calibration is a measure of how well the flow inputs are defined and how well the model routes flow (timing and magnitude) to the river's outlet.
2. *Water Surface Elevation Calibration*
   a. *Roughness Calibration—C*ompared model-predicted water surface elevations in the main channel to water surface elevations measured by level loggers at seven locations along the main channel. Adjustments to roughness coefficients were the primary mechanism for adjusting water levels up and down to create better agreement between measured and modeled water levels.
   b. *Flow Exchange Calibration*—Focused on calibrating the water levels in the lateral lakes and the direction and magnitude of the flow exchange between the main channel and the lateral lakes. During this step, changes were made to the river's connectivity with the lateral lakes and the local tributary flows that flow directly into the lateral lakes. Adjustments were only made when data were available to guide the changes and there were rational physical explanations for why the changes were needed.

5.2 Available Calibration and Validation Data

Data available for calibration and validation include water levels recorded at 17 locations and flow measured continuously at two locations. These locations are shown on Exhibit 15. Calibration was performed for the river from the downstream extent to the confluence. Because of data availability, the validation focused on the Meander Modeling Reach, which is the largest modeling reach of the Lower Basin, making up 82 percent of the entire modeled river length. The Meander Modeling Reach is also where the majority of the river/floodplain interaction occurs, and thus the likely location of the majority of the remedial actions. Water level and flow data are discussed separately in the following sections.

5.2.1 Water Level Data

Thirteen water level loggers were installed in the Springston, Killarney, and Dudley Reaches of the Lower Basin in April 2010. Six are in lakes; seven are located along the mainstem. Four additional water level loggers were installed in November 2011; two in the Dudley Geographic Reach and two in the Braided Geographic Reach. The loggers are all still actively recording data as of the time of this report. The loggers record water levels at 15-minute intervals. Data are downloaded from the loggers once a year in early winter when water levels are lowest and the loggers are most accessible.

Because the validation process requires an independent data set, data from the four newest water level loggers cannot be used during the 2012 WY (October 1, 2011, through September 30, 2012) validation process. Validation of the calibration reaches assigned to the four newest loggers will use WY 2013 data, when it becomes available.

Data collected from the initial 13 water level loggers between April 2010 and November 2011 were used for the WY 2011 (October 1, 2010, through September 30, 2011)[3] calibration of the Springston, Killarney, and part of the Dudley modeling reaches. These same 13 loggers were used for the WY 2012 validation of the lower three reaches.

Data collected from the additional four water level loggers were used for WY 2012 calibration and WY 2013 validation of the upper Dudley Reach and the Braided Reach. This did not affect the calibration of the lower three reaches since the Braided Reach is upstream of the Dudley Reach and does not have complex floodplain interactions that would affect routing of flows into the lower three reaches. Low lake and river water elevations dropped below many of the loggers in winter WY 2012, resulting in missing data for up to 10 weeks.

At six locations, the water level loggers were installed in pairs to measure the flow exchange between the river and the floodplain (lateral lakes). At the paired installations, the river logger is located on the mainstem near the tie channel that connects to the lateral lake. Having the river logger near the tie channel connection makes it possible to measure and calibrate the model at a critical location where flow exchanges with the floodplain. The corresponding lake logger is located within the lake; the specific location varies from lake to lake. The lake level logger not only measures the direction and magnitude of the flow exchange between the river and the lake, but it makes it possible to calibrate the lake levels before and after major flood events, which is critical to establishing the correct amount of available storage before a flood event. Paired loggers are installed at Thompson Lake, Blue Lake, Swan Lake, Cave Lake, Medicine Lake, and Killarney Lake. The locations of all 17 water level loggers are shown on Exhibit 15.

In order to accurately measure the slope of the water level between paired water level loggers, the elevations of the surveyed logger datums need to be precise. To achieve the best survey possible, the loggers were surveyed twice using global positioning system (GPS) technology, and then at the logger pairs, sight-leveling was used to increase the relative accuracy between the paired loggers. Given the difficult terrain and limited number of GPS satellites, absolute vertical survey accuracy for the paired loggers is at best 2 cm, and often greater than 2 cm. Leveling between all the water level loggers is not feasible given the distance between gages and the requirement that there be solid ground between loggers. The surveyed elevations were further checked by looking at the elevations being recorded by the loggers in late summer when the river has very little flow and the water level is nearly flat in the lower three reaches (backwatered). The paired loggers should be at the same elevation since the tie channels allow the water level in the lateral lakes to equalize with the river at low flow, at least for the lakes that have gages. This assumption is validated by the fact that all of the lake gages have recorded the 24-hour diurnal fluctuation, with negligible time delay, that is associated with power generation at the Post Falls Dam. This observation demonstrates that a strong hydraulic connection exists between the lateral lakes and the mainstem and thus the paired water levels should be nearly equal. Small adjustments were made to the lake logger datums based on this comparison.

A similar comparison was made for river loggers LL-01 through LL-09, LL-12, and LL-13, which should be nearly flat with a slight downriver gradient in late summer. A review of flow and stage information from the USGS gages at Harrison and Cataldo shows that the periods from August 14 through 21, 2011, and August 4 through August 10, 2012, have the lowest and most steady river flow, and the most steady lake level elevation before the fall lake elevation reduction. These periods should have the lowest and most linear river slope. Plotting the average water surface elevation of the river loggers for this period shows inconsistencies in river logger datum elevation. Because more accurate vertical survey data is not possible because of survey challenges, the level logger datums for LL-01 through LL-09 were corrected to a best-fit line through the average summer 2011 water surface elevations and forced through the average elevation at the Harrison gage. Because of the available data period of

[3] Water level logger data are available from April 2010 to present; however, because no high flow events occurred in 2010, the calibration process used only data collected in the 2011 water year.

record, LL-12 and LL-13 were adjusted using summer 2012 water surface elevations. These adjustments are shown in Exhibit 16. Lake loggers were adjusted consistent with the river logger pair so that the slope between lake and river logger during late summer is zero.

5.2.2 Flow Data

Two active USGS gages are in the Lower Basin and record flow at 15-minute intervals:

- **Harrison Gage:** USGS 12413860 Coeur d'Alene River is located at the Springston Bridge (River Mile [RM] 134.6) near Harrison, which records flow leaving the Lower Basin. Period of record: 2004 to present.
- **Cataldo Gage**: USGS 12413500 Coeur d'Alene River is located at the trail bridge near Cataldo at RM 162.9, which records flow in the Braided Modeling Reach. Period of record: 1920–1972, 1986 to present.

The two flow gages provide an opportunity to compare measured and model-predicted flows. The flow comparison provides a measure of the quality of the flow inputs to the model and quantifies the accuracy of the model's ability to route flows to the gage locations. The Harrison gage provides a more valuable comparison because it is located near the outlet of the model and therefore the flow comparison reflects the quality of the flow inputs and hydraulic routing for the entire Lower Basin. The Cataldo gage is located only about 5 miles from the confluence of the North Fork and South Fork confluence, so the comparison only reflects the accuracy of the flow inputs and hydraulic routing for the 5-mile reach upstream of the Cataldo gage.

No point measurements of instantaneous flow data are available at any other location. Such data would be valuable in testing how well the model predicts the magnitude of flow exchange between the river and floodplain at locations where significant overbank flooding occurs. There are plans to collect instantaneous flow data during future high-flow events.

Exhibit 24 summarizes the data available for calibration and the associated location in the model. Calibration gage locations are shown in Exhibit 6 and Exhibit 15.

5.2.3 Flood Event Characteristics for Calibration and Validation Periods

Because of the availability of level logger data and appropriately large runoff events, the model was calibrated using data collected during WY 2011 and validated using data from WY 2012.

Flood events in the Lower Basin vary greatly between those that occur in the winter and those that occur in the spring. In the winter, water levels in Lake Coeur d'Alene are variable, but are typically between 1.5 and 2.1 m below the summer water level. Because the lake creates a backwater effect, the river is also lower in the winter, at least in the reaches affected by backwater. Winter floods are also typically shorter in duration, usually lasting only a few days and are driven by rain or rain-on-snow. Spring floods are much longer in duration, usually lasting at least a week, and are driven primarily by snowmelt in the Upper Basin and occasionally from low elevation snowmelt, which when it occurs typically leads to more widespread flooding.

During winter floods, the river gradient is steeper, which creates higher velocities and shear stresses in the main channel compared to spring flood flows of equal magnitude. The exchange of flow between the river and the lateral lakes in the winter is limited by flow through the tie channels and only rarely goes over-bank. In the spring when flows are large enough and are sustained long enough for the water level in Coeur d'Alene to rise, overbank flooding occurs, which tends to dominate the flow exchange between the river and the lateral lakes and marshes.

Because winter and spring flood events are so different, it is critical that the model be calibrated and validated for each type of event. The 2011 and 2012 WYs captured a good mixture of winter and spring flood events. In WY 2011, two high-flow winter events occurred during low lake levels. The December 2010 flood had a peak flow of 537 cms at Cataldo; the January 2011 flood event had a peak flow of 934 cms at Cataldo. Because Lake Coeur d'Alene was low, as it usually is in the winter, no overbank flooding occurred during either of these winter event. The 2011 spring runoff event had a peak flow of 495 cms at Cataldo and overbank flooding in the Lower Basin was widespread, in part from the high water level in the lake. The WY 2012 winter lake levels were approximately 60 cm lower than those in WY 2011, resulting in slightly different winter river conditions for validation events. In WY 2012, three small winter events occurred during low lake levels, occurring between December and March, each with peak flows below 110 cms at Cataldo. A mid-March event occurred at moderate lake levels that caused the lake level to fill 0.55 m; this event had a peak flow of 428 cms at Cataldo. Two spring runoff events occurred at high lake levels: one at the end of March and one in late April. The March 2012 flood event had a peak flow of 824 cms at Cataldo; the April 2012 flood event had a peak flow of 763 cms at Cataldo.

Exhibit 25 characterizes runoff events in both the calibration and validation periods.

5.3 Flow Calibration

Flow calibration focuses on a comparison between measured and modeled flows at two locations: Harrison and Cataldo, with a greater emphasis on the flow comparison at Harrison since it includes flow from the entire Lower Basin. The flow comparison helps evaluate how well the flow inputs to the model are defined and how well the model routes those flows from their source through the river system.

The majority of flow inputs to the model (North Fork and South Fork) are measured and therefore reliable; however, flow inputs from tributaries within the Lower Basin are not measured and therefore must be estimated using the best available data. Flow inputs from Lower Basin tributaries were estimated using a hydrologic model (HEC-HMS), but were significantly modified during the flow calibration process.

Once the flow inputs are defined, the model routes those flows through the river system and calculates how much flow is exchanged with the floodplain during flood events. In order for the model to accurately route flow to its outlet near Harrison, it must calculate the complex flow exchange between the river and the lateral lakes and marshes since these features play a key role in attenuating peak flows and establishing how much flow stays in the main channel during flood conditions. Having an accurate understanding of how much flow stays in the main channel and how much flow is delivered to individual lateral lakes and marshes is a primary control on sediment transport processes in the Lower Basin.

Many factors affect hydraulic routing through the model and those are best evaluated using measured water level data, which is a separate step in the calibration process. The only adjustments made to the model during the flow calibration process were made to the tributary flow inputs. Changes made during other steps in the calibration process do affect the computed flow at Harrison and those effects were evaluated by continually checking the flow comparison at Harrison after all major adjustments to the model.

Because a portion of flows entering the basin are not gaged (approximately 10 percent), and thus are not precisely known, the accuracy of the estimated flow inputs needed to be evaluated during the flow calibration process. To evaluate how much flow should be coming from ungaged tributaries, the model was first run without tributary flows and the resulting flow comparison at the Harrison gage was examined. Exhibits 26 and 27 show the results from the model run without tributary inflows. The results show that without tributary inflows, the model under-predicts flow rates by approximately 8 percent (on average), but does predict the overall shape and timing of the hydrograph quite well. These results suggest that tributary flows do not have a major effect on the flow rates at Harrison. However, a comparison between model-predicted lake levels (without tributary inflows) and measured lake levels shows that the model greatly under-predicts lake levels without tributary inflows. This suggests that the tributary inflows have a first-order control on maintaining lake levels, which in turn controls the flow exchange between the river and the lateral lakes. This process is described in more detail in Section 5.4.2, Flow Exchange Calibration.

To evaluate how well the HEC-HMS model predicts the tributary inflows, a model run was performed that included the HEC-HMS tributary inflows and then the model-predicted flow rates at Harrison were compared to the measured values. Results from the run that include HEC-HMS inflows were consistently too high overall and introduced flashy peaks that are not reflective of what is being measured at the Harrison gage. This comparison demonstrates that the magnitude and volume of flows generated by the HEC-HMS model need to be reduced and the shape of the individual tributary hydrographs need to be smoother (less flashy).

To eliminate the undesirable flashy peaks observed in the HEC-HMS tributary flows, multiple average schemes were evaluated that would essentially flatten the tributary inflow hydrographs. The project team evaluated the effectiveness of averaging flows during the following time periods: 12 hours, 24 hours, 7 days, 14 days, 30 days, and 60 days. Based on a visual inspection and comparison of the resulting modeled hydrographs with measured flows at Harrison, the 14-day averaging scheme produced results that were most acceptable in terms of shape and timing of the hydrograph. Shorter averaging periods were not able to flatten the tributary hydrographs enough and the flashy peaks were still present. For longer time period averaging schemes, the flashy behavior was gone, but other portions of the hydrograph did not match as well as the 14-day averaging scheme. The averaging scheme only served to flatten the hydrograph; the volume of the original HMS-generated tributary hydrograph was conserved, which was shown to be too high. Therefore, additional adjustments were needed to reduce the overall magnitude and volume of flow.

After the 14-day averaging scheme was applied to the HEC-HMS-generated flows, the project team evaluated three alternative methods for scaling down the flows:

1. Time-series scaling factors, where each of the tributary flows are reduced by a factor between 0 and 1 at each 15-minute time step. The time-series scaling factors were developed based on the difference between the modeled flows at Harrison without any tributary flow inputs and the measured flow at Harrison. The difference should reflect the flow that should be coming from tributaries. The scaling factors were then applied to adjust the HEC-HMS-generated flows so they would more closely match the measured flow differential. The time-series scaling factors were computed using the following equation: $(\text{USGS} - \text{Model}_{\text{no tributary}})/(\text{Model}_{\text{tributary}} - \text{Model}_{\text{no tributary}})$.
2. A monthly scaling factor, developed from the monthly average of the time-series scaling factors from 2004 to 2011. Monthly scaling factors range from 0.125 to 0.668.
3. A constant scaling factor developed from the average of the time-series scaling factor between 2004 and 2011. The constant scaling factor is 0.375.

All three of the scaling schemes were quite effective at achieving the necessary level of flow reduction. Alternative 1, the time-series scaling factor scenario, produced the best results, which is an expected outcome since this scheme makes unique adjustments at each time step based on the measured flows at Harrison. However, the time-series scaling factors can only be applied to time periods after 2004 because that scheme relies on data collected at the Harrison gage, which was installed in 2004. Therefore, it cannot be applied to any flood event that occurred before 2004, such as the 1996 flood (approximately 100-year recurrence interval), which is a critically important event to consider when evaluating remedies.

Alternative 3, the constant scaling factor, performed nearly as well as the time-series scaling factor scheme and performed better than the monthly scaling factor scheme. The constant scaling factor scheme was determined to be the best approach because it effectively reduces the HEC-HMS flows and produces good agreement between measured and model flows at Harrison, and it can be applied to time periods before 2004.

In summary, the tributary flows generated by the HEC-HMS model were too high and too flashy. To address these two issues the hydrographs were smoothed (flattened) by averaging them over a 14-day period. Then they were reduced by a constant scaling factor of 0.375. These adjustments significantly alter the hydrographs generated by the HEC-HMS model and the fact that these adjustments are necessary is an indication that unadjusted flows from the HEC-HMS model is unreliable for predicting flows in this setting. Although the unadjusted hydrographs generated by the standard HEC-HMS model are not reliable, the adjustments made to them appear to create a more realistic estimate of the tributary inflows.

Modifications to the HEC-HMS tributary inflows are summarized in Exhibit 27. This exhibit shows the progression of model flows at Harrison[4]: using no tributary flows, using the full unadjusted tributary flows, using the 14-day averaged HEC-HMS tributary flows, and the final result using the 14-day averaged flows scaled by 0.375. In addition to the final flow results at Harrison shown in the top two graphs of the exhibit, the total ungaged tributary flow is shown in the bottom two graphs. Close-up graphs on the right are indicated by similarly shaded

[4]The calibration process includes flow calibration, roughness calibration, and flow exchange calibration. The entire process was completed twice as discussed in Section 5.1. The results shown on Exhibits 31 through 44 are from the second and final round of calibration.

boxes. The final tributary flows used in the model, shown graphically in Exhibit 19, are included electronically as DSS files in Attachment C.

Results from the flow calibration process show that the model is capable of replicating flow rates at Cataldo and Harrison quite well overall. For the 2011 calibration period, the model replicates the spring hydrograph within 0.9 percent on average over the entire flood event, though the modeled peak is higher than the measured peak (15.5 percent). For the spring runoff event in 2008, the model is over-predicting flow rates on the rising limb of the hydrograph and under-predicting flows on the falling limb of the hydrograph. The most challenging events for the model are the short-duration flashy winter floods, which cause river levels and flows to rise rapidly. The model is over-predicting winter peak flows for events modeled in WY 2011. The observed over-prediction in flow during the winter 2011 floods and the spring 2008 flood are likely caused by inaccuracies in hydraulic routing—the model should be sending more flow to the floodplains, especially on the rising limb, and storing the water longer. It is possible that by modeling the floodplain as a series of lateral structures (weirs), storage area connections (weirs), and storage areas, modeled flow moves across the floodplain faster than in reality. This aspect of the model is discussed in greater detail in the Reliability section. Without higher spatial resolution water level and flow data, it is impossible to know where adjustments should be made to the model. Data collected in future years may help guide additional model adjustments that could improve the flow calibration. Although some flow residuals remain, the model calibrates quite well to flow at the two gage locations, especially given the complexity of the Lower Basin.

Completion of the flow calibration processes marks the end of all adjustments to model inflows (boundary conditions). The next step in the calibration process was to adjust model parameters so that modeled water surface elevations closely matched measured water levels at gaged locations.

5.4 Water Surface Elevation Calibration

The purpose of water surface elevation calibration is to adjust model parameters such as roughness and tie channel geometry so that the model best replicates conditions observed or measured in the field. By calibrating and then validating the model, the user has greater confidence that the results for conditions and periods outside of the calibration period reasonably reflect what would be observed or measured in the field.

Because the differences between the modeled and measured water surface elevation are small relative to the range of natural fluctuation of water surface elevations, calibration focuses on the *residual,* which is defined as the difference between measured and modeled water surface elevation. Overall, the objective of calibration is to minimize the residual in both the river and lake levels. In addition to minimizing residual at individual water level loggers, the calibration also looked at the difference in water surface elevation between river and lake water level logger pairs. The difference in elevation between the river and lake level at a given location indicates the direction of the flow exchange, and the magnitude of the difference in elevation is a measure of the magnitude of flow being exchanged between the river and the respective lake.

5.4.1 Roughness Calibration

The primary mechanism for controlling model-predicted river levels is to adjust the channel and floodplain roughness coefficients, which are used to estimate energy losses along the length of the river. Roughness coefficients can be adjusted at each individual cross section or uniformly for multiple cross sections over a defined reach length. Higher roughness coefficients produce higher water levels and vice versa. The methods used to define initial roughness coefficients for the Lower Basin model before calibration are described in Section 4.4.2.

Flow resistance is known to vary as a function of stage and flow. In some cases, flow resistance can increase with increasing water levels because flow becomes hindered by vegetation as flow rises and moves out onto the floodplain. In other cases, flow resistance decreases as flow depths become greater relative to the height of various flow obstructions or the flow obstruction heights may be reduced by hydraulic forces (for example, grasses can get laid down by high flow velocities, dunes can become washed out, etc.). It is therefore important to have a modeling approach that allows for stage- and flow-dependant roughness variations.

For the Lower Basin model, stage-dependant roughness variation is handled by the spatial distribution of roughness coefficients (mapping methods described in Section 4.4.2)—as river levels rise and flows spill out onto floodplains with active conveyance, the model will utilize roughness coefficients that are reflective of the vegetation present at unique locations. HEC-RAS uses a weighted average of the constant user-defined Manning's n coefficient along the wetted perimeter in its formulation of the momentum equation; it does not vary as a function of stage or flow except for the change in weighted roughness due to difference in wetted perimeter. The friction slope term is a function of both stage and flow, but the Manning's roughness coefficient is not. To better account for flow-dependant resistance, HEC-RAS has an optional function that allows the user to scale roughness coefficients as a function of the local flow rate at individual cross sections.

HEC-RAS does not have the capability to adjust the spatial distribution of roughness coefficient as a function of flow or stage, so the spatial distribution of roughness coefficients is therefore fixed. The only available adjustment options are to change the initial roughness values or to scale them during the simulation as a function of flow. And, because the initial roughness values were establish based on reasonably reliable information (aerials, vegetation maps, and bathymetry) and are reasonable for this site, the initial roughness values were not adjusted during the calibration process. The only roughness calibration parameters that were adjusted were the roughness coefficient flow scaling factors.

Roughness coefficient scaling factors were applied on a sub-reach-scale (termed calibration reaches) based on the location of the river level loggers (see Exhibit 15 for a map of these loggers, and Exhibit 24 for a list of these loggers). For example, the Killarney Calibration Reach extends downstream from the water level logger located at the mouth of the Killarney Lake tie channel to the next downstream water level logger located at Swan Lake. Unique scaling factors for each calibration reach were established through an iterative process of running the model, plotting the resulting water level residuals against flow, visually comparing measured and modeled water level time-series, evaluating the trends, and then making adjustments to the scaling factors. This process was repeated numerous times until the residuals were reduced to the extent possible. Roughness scaling factors were allowed to vary no more or less than 0.5 (± 50 percent change to initial roughness coefficient), although most adjustment were much smaller. The process focused initially on the downstream calibration reaches and progressed in the upstream direction. River levels above the Dudley gage were not recorded in WY 2011, and thus were not calibrated during this process. Calibration reaches above the Dudley gage will be calibrated using water level data collected in 2012.

The final calibrated roughness coefficient flow scaling factors are listed by calibration reach in Exhibit 28. Resultant roughness coefficients composited at each cross section and used by the model for the calibration period are shown in Exhibits 30 and 31. Exhibit 30 shows composited roughness coefficients as a function of flow for each calibration reach. Exhibit 31 shows composited roughness coefficients for three different flow rates as a function of longitudinal distance along the channel.

The final flow roughness scaling factors are generally higher for low flows, and lower for high flows, representing the decrease in resistance as flow depths become greater relative to flow obstruction height. Most reaches show a linear trend in weighted roughness coefficients as a function of flow, which is to be expected. Deviations and scatter around these linear patterns are mostly the result of differences in water surface elevations caused by seasonal variations in backwater; water levels are lower in the winter for a given flow rate compared to water levels in the spring. This seasonal difference in water levels leads to differences in the wetted perimeter, which results in a difference in the weighted roughness value for the same flow rate.

Weighted roughness values generally increase in the upstream direction as expected, since roughness heights associated with both bed forms and grain size also increase in the upstream direction. Two exceptions to this upstream increasing trend in weighted roughness are one near Thompson Lake and one near the dredge pool. The roughness values near Thompson Lake and the downstream boundary are higher than the adjacent upstream reach. This is either a result of inaccuracies in the survey datum for the Thompson Lake water level logger or discrepancies between the USGS Harrison gage datum used to define the downstream boundary condition and the Thompson Lake datum. Upstream of the Dudley Reach weighted roughness values drop dramatically for a distance of approximately 5,000 m; this drop is believed to be a result of inaccuracy of the surveyed datum assigned to the dredge pool logger. The method for adjusting water level logger datums described in Section 5.2.1 cannot be applied to the dredge pool logger because it is located upstream of the summer backwater. The actual datum of the dredge pool logger is likely higher than the survey data suggest; however, because no additional data or evidence beyond model predictions exist to justify changes to the surveyed datum, the datum was not adjusted.

The calibrated water levels replicate observed river levels quite well for most of the time, although there are periods where large residuals occur. The following are observations relating to the final river level calibration:

- In general, the model replicates water levels more accurately during spring runoff events when river levels change more slowly compared to winter floods where river levels rise and fall more rapidly.
- Despite higher roughness scaling at low flow rates, many river gages tend to show a small negative residual (approximately -1 to -3 cm) during low flow periods. The fact that this negative residual exists no matter how high of a roughness value is applied suggests that small inaccuracies remain in the water level logger datums.
- Peak water levels match very well in terms of magnitude and timing, except for periods of considerable overbank flooding. This demonstrates that the model is routing the flood wave propagation accurately.
- Water level residuals are greatest for the gages located furthest from the downstream boundary at Harrison. This is because more complex flow exchange occurs in those reaches, and residuals tend to propagate and amplify farther from the downstream boundary.
- For both flow at Harrison and water surface elevation at the river loggers, the largest residuals occur on the rising limb of the hydrograph when water levels are rising rapidly (approximately 2 to 5 cm per hour). The modeled water levels rise at the same rate as the measured values but are lagging behind by approximately 2 to 6 hours, leading to instantaneous residuals on the order of 15 cm for a period of 1 to 2 days on the rising limb of winter hydrographs. It is difficult to know with certainty why this is occurring, but there are several possible explanations. The model could be routing the flood wave too slowly, producing lower instantaneous flows at a given location and time, but this seems unlikely since the modeled flows at Harrison match quite closely in time with the measured values (though it is difficult to detect timing errors that are on the order of only a few hours). A second plausible explanation is that the flow roughness scaling factors are biased toward flood conditions with greater backwater influence, since those occur more frequently and thus receive more weight in the regression analysis used to develop the flow roughness scaling factors. Roughness factors should be higher on the rising limb of flashy winter events, because the flow depths are lower relative to the roughness height of the bed. However, the flow roughness scaling factors were developed using calibration data from the entire water year, which is dominated by flood conditions with greater water depths (resulting from higher backwater during spring runoff, which occurs for a longer period of time). Thirdly, natural lake levels and operations of Post Falls Dam create seasonal variations in backwater conditions that leads to a range of water depths for a given flow rate, and the method of using flow roughness scaling factors cannot account for a range of flow depths.

Results of the river level calibration and validation are summarized in Exhibits 33 and 35 through 47. Exhibit 33 shows a comparison between modeled and measured river levels for WY 2011, which demonstrates good agreement at a coarse scale. To illustrate more clearly the differences between model and measured river levels, the residuals are plotted on part *a* of Exhibits 35 through 45 as a time-series and shown in relation to the measured river stage. To quantify and document the duration at which residuals persist, they are plotted as a function of a percentage of time in Exhibits 46 and 47. Exhibit 32 shows river level profiles from the HEC-RAS model in comparison to measured river levels for a series of select flows.

5.4.2 Flow Exchange Calibration

Water levels in the lateral lakes rise and fall according to the net difference between all flows coming into and leaving the lake. The sources of flow include local tributary runoff, flow exchanged in both directions with the river through its connecting tie channel, and overbank flow, which is only exchanged with the river at high flow. Lake levels control several key hydraulic processes in the Lower Basin. They determine the amount of active storage available before a flood, which determines the amount of flow attenuation that can occur during a flood. This affects hydraulic forces in the main channel, because flows in the main channel are reduced as water spills into the lateral lakes. Flow is exchanged with the river most frequently through the tie channels (year-round), but the magnitude of flow exchanged through overbank flooding is much greater than the flows exchanged through the tie channels. The flow exchange processes are driven by the water level gradient between the river and the lateral lake. The model must be able to predict lake levels accurately in order to predict the direction of the flow exchange.

Many model parameters could be changed to calibrate lake levels; however, isolating the correct variable cannot always be accomplished with complete certainty. To determine the most appropriate parameter to adjust, the project team studied the timing of residuals in relation to river conditions (flow and level). This helped determine the flow sources and flow paths at that time, which guided interpretation of the most likely source of error. When making adjustments, the team considered which model inputs were likely to have the greatest level of uncertainty (see discussion of uncertainty in Section 6.0 and in Exhibit 51). Through this process it was found that flow through the tie channels seemed to be the most likely source of model residuals and that geometry has a high degree of uncertainty associated with it. This is because the model can only represent the tie channel with a single cross section, when in reality the tie channels have a length to them and variable geometry over that length, and the available survey data are relatively coarse in those areas. Therefore, the project team focused primarily on tie channel geometry during the lake level and flow exchange calibration process.

Initial model results showed that lake levels were dropping too quickly and too far below measured values, especially during low flow periods. It appears that this was primarily because of inaccuracies in the tie channel geometry, which was initially extracted from cross sections located under the bridges that span the tie channels where local scour holes are present. This resulted in tie channel geometry that was too low and sometimes too wide at the base of the cross section, which was allowing too much flow to drain out of the lake (especially during low flow periods), and was also affecting high flow river-lake exchanges because the lake levels were too low when flooding began. To slow the draining process, the inverts of the tie channel were adjusted and sometimes the width of the low flow portion of the channel was adjusted based on careful inspection of the terrain model, which includes survey data along the length of the primary tie channels. Changes to tie channel geometry were conducted incrementally, so that the effects could be isolated, and were only made in cases where the geometry adjustments were justified based on field survey data. All changes made to tie channel geometry are shown in Exhibit 29.

Flow exchange residuals that exist during high flow periods are more challenging to isolate and therefore defensibly correct because during high flow conditions the lake level is controlled by overbank flow exchanges that occur in both directions (to and from the lake) over a large area. It is, therefore, not possible to isolate the portion of the bank that may be inaccurately describing overbank flow paths. The banks are defined using LiDAR data, which are generally believed to be of good quality. However, all LiDAR data is affected by thick vegetation and as a result often bias the topography data high. Another source of uncertainty associated with overbank flow is how the banks are modeled in a 1D model. They are treated as irregular weirs that define the shape of the bank line reasonably well but cannot adequately account for dense vegetation that hinders the flow exchange process. Moreover, the model does not account for any flow resistance in areas defined with storage areas, which is the majority of the floodplain areas. This is a fundamental limitation of the 1D model and is discussed in depth in subsequent sections on model reliability and uncertainty. Because not enough data were available to guide and justify changes to the bank geometry, no changes were made to original bank geometry during the calibration process. Similarly, because independent surface data is not available for comparison, the magnitude of uncertainty in bank elevation is unknown. Large differences in bank elevation would undoubtedly have large impact on overbank model flows and thus overall model results; small differences would likely have little impact.

Results from the lake level and flow exchange calibration are shown in Exhibits 34 through 39 and in Exhibits 48 and 49. The measured flow exchange is defined as the difference in lake and river water levels. A positive water level difference represents flow from the lake to the river; negative values represent flow from the river to the lake.

Key observations regarding lake level and flow exchange calibration include the following:

- The lake levels are generally in good agreement with measured values, but the lake residuals are generally higher relative to the river residuals both in terms of magnitude and frequency. More variables are involved in controlling the lake levels, and more uncertainty is associated with the controlling variables. Isolating the controlling variables is difficult and often not possible with currently available data. The lake level residuals are expected to be greater than those of the river, because the errors from the river levels propagate to the lakes. When combined with other sources of error, such as those associated with inaccurate tributary inflows and flow exchange from the river, it creates a larger total error.
- The model replicates the direction and magnitude of the flow exchange quite well most of the time.
- Lake levels at low flow periods are quite accurate most of the time. However, large residuals occur when the river levels are at their lowest (due to draw down of Lake Coeur d'Alene) and the lakes become elevated (relative to the river). When the lakes become elevated above the river, water drains from the lakes through surface (and to a much lesser degree, subsurface) flow paths, which are poorly defined for these conditions.
- Lake level residuals are greatest during winter floods, specifically on the rising limb of the hydrograph. This observation correlates strongly with the occurrence of under-predicted river levels.
- Lake level and flow exchange residuals are largest at the sites that have multiple channels and connections to both the river and adjacent lateral lakes. Cave Lake and Medicine Lake, for example, each have their own connection to the river and are connected to each other. Also, Medicine Lake has two flow constrictions (embankments with bridge openings) along its tie channel, and Medicine Lake receives flow from a managed flow diversion (Robinson Creek). Because of these complexities, these lakes have the highest lake level and flow exchange residuals. It appears that most of the remaining residuals are associated with inaccuracies in the flow coming from local tributaries.
- Negative lake level residuals occur when water levels are at their highest, which generally coincides with the occurrence of overbank flooding. This is likely the result of neglecting flow resistance across the floodplain. When water levels overtop the river banks, flow spreads out across the floodplain and experiences a large increase in flow resistance that leads to an increase in water depth. This is a process that cannot be accounted for in the 1D model.

5.5 Validation Process

Flow at the Harrison and Cataldo USGS gages was calibrated to WY 2011 and validated using WY 2012. Water surface elevations in the lower three geographic reaches (Springston, Killarney, and Dudley) were calibrated to WY 2011 and validated using data from WY 2012. Water surface elevations in the Braided Reach were calibrated to WY 2012 data and will be validated with WY 2013 data when available. This section covers flow validation and water surface elevation validation of the lower three geographic reaches only.

The goal of model validation is to validate the performance of the model using data independent of that used for calibration, to demonstrate that the model can be applied to other flood events of similar magnitude with a level of reliability equal to that of the calibration period. For this project, model validation is considered successful if the residuals from the validation run have similar magnitude, timing, and frequency compared to residuals from the final model calibration. Model validation also provides a second data set for which to describe the model's strengths, weaknesses, and limitations.

5.5.1 Flow Validation

Flow calibration and validation figures can be found in Exhibits 26 and 27. As in the calibration period, flows in the validation period closely track measured flows at Cataldo and Harrison. At Cataldo, the flow magnitude and timing match very well. The largest residuals occur during spring peak flow, but the residuals are less than 2 percent and slightly better than the residuals observed in the calibration period.

At Harrison, the magnitude and timing of modeled flows match quite well most of the time, consistent with calibration residuals. However, the modeled peak flow during the spring runoff occurs too early and is too high. This was also observed in the 2008 model simulation. The over-prediction of flow coincides with the occurrence of overbank flooding in many areas, specifically the Killarney Lake and Swan Lake Reach. This over-prediction is believed to be caused by the model routing too much flow onto the floodplain and routing floodplain flows downstream too quickly (instantaneously in some cases). This causes water to be routed to the outlet too quickly and the attenuation effect of the lakes is under estimated. This is described in more detail in Sections 5.7 and 6.

The residuals observed for the validation period are similar to those observed for the calibration period. Exhibit 50a shows a statistical summary of the flow residual at the Cataldo and Harrison gages.

5.5.2 Water Surface Elevation Validation

Results from water surface elevation validation (WY 2012) and calibration (WY 2011) are presented in parallel to illustrate the comparison of the two (Exhibits 33-v through 49-v). In addition, Exhibit 50b shows a statistical summary of the water surface elevation residual at each of the gages.

In general, the water surface elevation residuals for the validation period have similar magnitude, timing, and frequency compared to the residuals of the calibration period. One important aspect in the comparison of these two sets of results is the difference in winter levels for Coeur d'Alene Lake. The winter low lake level for WY 2012 (the validation period) was 58 cm lower than the winter low lake level for WY 2011. The WY 2012 winter lake levels were the second lowest observed in the 9-year record at Harrison (the lowest was 2 cm lower, in WY 2006) and the ninth lowest observed in the 46-year record at Coeur d'Alene. In addition, the lake level in the winter of the calibration period rose above summer pool levels on three separate occasions, while the lake level in the validation period stayed low for the entire winter. Because the model was calibrated to the higher winter WY 2011 lake levels, the model does not perform as well during the uncharacteristically low WY 2012 winter. This is especially true for the modeled lake loggers elevations, which given the WY 2011 model calibration remain perched well above the modeled and recorded levels of the river in WY 2012.

The difference between the calibration and validation mean and median residuals is less than 1.5 cm, except for a few isolated cases. For example, the difference between the validation mean residual and the calibration mean residual is more than 1.5 cm for the Swan Lake, Cave Lake, and Medicine Lake lake loggers, which experience a large residual for the majority of the 3 months of low winter levels. This is especially true for Cave Lake, which logger data shows stays perched nearly 35 cm above the modeled elevation during the low WY 2012 winter. The median validation Cave Lake residual is equal to the calibration residual. However, these prolonged large residuals control the mean residual.

The validation mean residual is also more than 1.5 cm different than the calibration mean residual at Dudley. The modeled water surface elevation at Dudley is consistently low during low flow periods, and because the modeled water surface elevation at Dudley is consistently low during low flow periods and low flow conditions occurred more frequently in WY 2012 than in WY 2011, the validation mean and median residuals at Dudley are 1.5 cm and 2.1 cm lower than the calibration residuals.

Overall validation period residual frequency also tends to be similar to that from the calibration period. River logger residual frequency for winter events in the validation period shows an overall higher residual for many gage locations due to the extreme low lake elevation and associated large quantity of missing river logger data (because of water levels dropping below logger elevations) during these winter events. Lake logger residual frequency for winter events in the validation period shows significant variance from the calibration period due to the lake connections not being calibrated to such low winter river levels.

5.5.3 Validation Recommendations

Validation residuals are generally consistent with those observed for the calibration period, especially when river conditions are similar. Validation results demonstrate that the model routes the flood wave propagation very well except when considerable overbank flooding occurs and the reasons for that residual is related to fundamental limitations of the 1D model. The largest discrepancies in water levels observed during validation occur during extreme low lake (and thus river) elevations. River level residuals are comparable to those observed in calibration. Lake levels during validation flood events are comparable to those observed in calibration; however, larger residuals were observed during the winter when lake levels were extremely low. No adjustments to the model are recommended at this time.

Because of data availability, the four loggers installed in January 2012 (LL-10-R, LL-11-R, LL-12-R, and LL-13-R) were not validated. When WY 2013 data is available, these four loggers should be validated.

5.6 Sensitivity Analysis

Sensitivity analyses were performed at multiple points during model development and calibration. In this context, sensitivity analysis refers to an evaluation of how model results change based on discreet individual changes to the model. Some of these analyses were performed explicitly and quantitatively, while others were more implicit and qualitative, based on an understanding of underlying model equations and construction. Sensitivity analysis is closely related to uncertainty analysis in that uncertainty about elements to which the model is extremely sensitive leads to high uncertainty in model results, while uncertainty in elements to which the model is not sensitive do not lead to higher uncertainty in model results. A comprehensive and detailed description of the model's sensitivity to specific input parameters and the associated uncertainty are summarized in Exhibit 51. Elements to which the model is most sensitive include:

- **Downstream Boundary Condition**: The Coeur d'Alene Lake level determines the degree of backwater effects for two-thirds of the model, affecting flow and water surface elevations throughout the model.
  - High sensitivity; low uncertainty for periods after 2004, moderate uncertainty for periods prior to 2004
- **Upstream Boundary Condition**: Flows from the North Fork and South Fork comprise 90 percent of the flow entering the model. All model results are thereby extremely sensitive to these inputs. However, these inputs are measured and thus have a low level of uncertainty.
  - High sensitivity; low uncertainty
- **Ungaged Tributary Flows**: The model outputs that are most sensitive to tributary flow inputs are water levels in the lateral lakes, the direction and magnitude of flow exchange between the river and the lateral lakes, and flow rates in the main channel, especially for the areas furthest downstream.
  - High sensitivity; high uncertainty
- **Tie Channel Geometry:** The geometry used to define the tie channels (the width/flow area and the invert) has a first-order control on water levels in the lateral lakes and the magnitude of flow exchanged between the river and the floodplains. The invert strongly affects the rate and extent of draining, especially during winter months. The width and flow area are more important during moderate flows when river levels are rising and falling rapidly, creating large head gradients between the river and lateral lakes. The model is less sensitive to tie channel geometry at high flows because of a weaker head gradient, and overbank flows are much larger and tend to dominate the river-lake exchanges at high flow.
  - High sensitivity; moderate level of uncertainty
- **Cross Section Geometry**: Cross section geometry affects all hydraulic results. Channel cross section geometry is derived from high-density and accuracy multi-beam and single-beam bathymetry, and LiDAR data.
  - High sensitivity; low uncertainty
- **Bankline Geometry**: The geometry used to define the channel banklines (lateral structures in the model) provide a first-order control on the extent, location, magnitude, and frequency of overbank flooding.
  - High model sensitivity; moderate uncertainty

- **Channel and Floodplain Roughness**: Channel conveyance, water surface elevations, floodplain flow, and final calibration parameters are all dependent on channel and floodplain roughness.
  - High sensitivity; moderate uncertainty

Implications associated with model elements that have both a high degree of sensitivity and high level of uncertainty are discussed in Section 6.

5.7 Reliability

The model's reliability refers to the level of accuracy and robustness for specific model outputs. Reliability refers to model outputs, while uncertainty of model inputs and model processes is discussed in Section 6.0. This section summarizes the model's strengths and weaknesses and quantifies reliability for key model outputs.

Strengths

- Flood wave routing is highly reliable, especially when flows are at or below bankfull conditions. Flood wave routing is less reliable when significant overbank flooding occurs because of a "shortcutting effect" that occurs in the reach between Killarney and Swan lakes. Floodplains that are modeled using storage areas connected to the channel with weirs transfer water between the connected areas nearly instantaneously with no accounting for flow resistance or flow attenuations. For example, in cases where the floodplain has an upstream "inlet" and downstream "outlet," flows that enter the floodplain "inlet" can be instantaneously routed (by the model) many miles downstream through the floodplain, which results in an early and high estimation of peak flows at Harrison when the overbank flooding is significant. Notably, this only occurs in the reach between Killarney and Swan lakes. Overall, the timing and magnitude of flow routing is quite reliable, which is critical for using the model to support flood stage data collection efforts.
- The model is able to replicate water surface elevations along the river with a high degree of reliability most of the time. The level of reliability has been quantified by reporting water surface elevation accuracy as a percent of time and reported separately for winter floods, spring floods, and the entire WY. No one number can be used to summarize the reliability of predicted water surface elevations, and these results are best viewed graphically. A series of residual-duration plots are included in Exhibits 46 and 47. A few trends can be seen in the residual duration plots: reliability of water surface elevations decreases with distance from Harrison, and water surface elevations are more reliable during spring floods compared to winter floods.
- The locations and timing of overbank flooding can reliably be predicted by the model. Accurate river level predictions can be used to asses when and where overbank flooding will occur. This can be assessed within or outside of the model. It is unclear at this point whether the model can be relied upon for predicting the magnitude of flow that leaves the main channel and flows across the floodplain, since instantaneous flow data are not yet available to validate the model predictions. This is discussed further as a potential weakness.
- The model reliably predicts the direction and magnitude of the flow exchange through most tie channels; flow exchange predictions are less reliable in Cave and Medicine lakes because multiple connections make it difficult for the 1D model to simulate.
- Because the model is reliable for predicting water levels and flows (when significant overbank flooding does not exist), it can therefore be relied upon for characterizing the associated hydraulic parameters such as average velocity and average bed shear stress.

Weaknesses

- The model has trouble predicting lake levels during rare winter periods where river levels are extremely low and the lateral lakes become elevated above the river.
- When significant overbank flooding occurs in the reach between Killarney and Swan lakes, floodplain flows are routed downstream too quickly, which results in a peak flow prediction at Harrison that is early and high.

- A second concern related to the routing of flows through the floodplain between Killarney and Swan lakes is the potential that model is sending too much flow out onto the floodplain. While the flow pathways onto and off of the floodplain are believed to be approximately correct, the concern is primarily related to the magnitude of flow sent to the floodplain in this reach of the model. At high water levels (above bankfull), the model predicts that flow spills into Strobl Marsh and Killarney Lake over a bankline distance of approximately 6 kilometers (km). Flows are incrementally delivered to the floodplain and after 6 km of spill to the floodplain, the floodplain carries 60 percent of the total flow. Maximum floodplain delivery rates observed in the model results in the Strobl Marsh vicinity are 10 percent of the total flow per km of bankline, and the exchange happens uniformly over the 6 km. After 6 km of losses to the floodplain, flows begin to return to the channel incrementally over a distance of 2 km. However, not all of the flow returns to the channel; some flow remains in the Blessing Slough channel that parallels the river and discharges into Swan Lake. At Swan Lake a similar phenomenon occurs, with 60 percent of the total flow leaving the channel over a distance of 5 km (12 percent of total flow per km of bankline) and then returns to the channel incrementally over a distance of 4 km. These flow pathways and the associated changes in channel flow are shown in Exhibit 52.
- When viewed from a maximum value perspective (60 percent), this seems like an excessive amount of flow conveyed by the floodplain; however, the floodplain is conveying less than 60 percent at the majority of locations. Several explanations for why these modeled results are more or less likely to be correct are discussed here as follows:
  - Explanations that support the high floodplain flow rates predicted by the model include:
    - Flows are being conveyed to the floodplain slowly over a very long distance.
    - The water surface elevation is sustained at a high level by backwater and does not drop as flows are lost to the floodplain, as would occur in a free-flowing river.
    - The floodplain is huge and has the potential to store and convey a high volume of water.
  - Points that dispute the model results are based primarily on engineering judgment. The relative percentage of total flow conveyed by the floodplain appears too high and the model predicts a reduction in velocities as flows leave the main channel.
  - The current opinion of the model development team is that the model is correctly predicting the flow pathway (to and from the floodplain) and timing, but it may be over-predicting the magnitude of flows delivered to the floodplain. Essentially, the model is predicting the exchange for the right reasons, but it is not accounting for flow resistance and flow obstruction on the floodplain that would reduce the flow spilling over the banks and reduce floodplain conveyance capacity. Instantaneous measurements of flow are needed at high flow rates to compare against model-predicted channel flow rates. These data are planned to be obtained during the next high flow event. In the meantime, the 2D hydraulic model can be used to evaluate floodplain dynamics in this reach. If it is found that the 1D model is sending too much flow to the floodplain at high water level, the model results will not be reliable for characterizing hydraulic parameters such as velocity and shear stress in the reach affected by the floodplain flow over-prediction.

6.0 Assumptions, Limitations, and Uncertainty

Multiple assumptions, limitations, and uncertainties are associated with the Coeur d'Alene 1D model. Some of these are related to limitations of the HEC-RAS modeling platform, and others are specific to the input data available for the Coeur d'Alene model. Uncertainty and related sensitivity associated with specific model elements is discussed in detail in Exhibit 51. The following list summarizes more general assumptions, limitations, and high uncertainties.

- Related to the HEC-RAS modeling platform:
  - **1D Flow Assumption**: As a 1D model, HEC-RAS assumes that flow is perpendicular to defined cross sections (flow in one dimension only). This is generally a reasonable assumption for in-channel flow, but

when flows go over bank, the flow direction is strongly two-dimensional and 1D models have a difficult time simulating this process. A limitation related to the 1D nature of the model is that all hydraulic results are both depth and width averaged, providing only a single value at a given location.

- **Neglecting Flow Resistance in Floodplains:** Flow conveyance in the floodplains cannot be simulated accurately with 1D flow assumptions, so the floodplains are treated as storage areas connected to the river and adjacent floodplains with weirs. The model only tracks flow into and out of the storage areas and the associated water surface elevation. Flow resistance from vegetation, which can be significant in floodplains, is not accounted for with this modeling approach. As a result, the model routes flows to, from, and through the floodplain instantaneously and does not account for the increase in water surface elevation and water surface slope associated with floodplain flow resistance. The approach of using storage areas works quite well in areas where flow is only exchanged laterally and does not flow downstream on the floodplains; this scenario exists in many locations in the Lower Basin (such as Blue Lake and Black Lake). The weaknesses of this approach are evident in cases where downstream conveyance occurs in the floodplain, or where flow can enter the floodplain at an upstream location (or reach), travel downstream along the floodplain (instantaneously), and then re-enter the channel downstream. The instantaneous routing of flow through the floodplain creates a "shortcutting" effect, leading to peak flows downstream that are too high and occur to early. This occurs during high flow at two locations in the Lower Basin: Killarney Lake to Blessing Slough, and again at Blessing Slough to Swan Lake.

- **Hysteresis:** Seasonal operations of Post Falls Dam create conditions where a range of water depths exist for a given flow rate. Flow resistance in the channel is a function of both water depth and flow rate. The equations used by HEC-RAS to compute the friction slope use depth (in the form of hydraulic radius), flow rate, and the Manning's roughness coefficient. The roughness coefficient is the only parameter in the flow resistance formulation that can be adjusted and it can only be adjusted as a function of flow rate. While the flow resistance formulation is a function of both stage and flow, the parameters cannot be calibrated for both stage and flow, and thus cannot be calibrated to the site-specific hysteresis conditions. The roughness coefficients are calibrated as a function of flow and the scaling factors were developed through regression analysis. The scaling factors are biased by the flood conditions that occur most frequently, which are the spring runoff events resulting from longer flood durations. As a result, predicted water surface elevations are less reliable for winter events compared to spring events.

Many of the limitations of the 1D model will be overcome with 2D modeling, which is currently being constructed and calibrated. See the Modeling Workplan (CH2M HILL, 2011) for a description of how the 1D and 2D models will be used together.

- Limitations and uncertainties related to input data:
  - **Ungaged Tributary Inflows**: Flows from the ungaged tributaries entering the river between the confluence and Harrison are not known (gaged). A hydrologic model was used to develop modeled flows. The calibration process revealed a high level of uncertainty associated with model-predicted tributary flows. They appear to be too high and too flashy. Adjustments were made to predicted tributary flows at a gross scale, but considerable uncertainty still exists associated with these flows. Uncertainty associated with tributary flow inputs translate into uncertainty in model-predicted lateral lake levels and river-floodplain flow exchange.
  - **Downstream Boundary Condition Prior to 2004:** The water surface elevation data used to define the downstream boundary are only available at the Harrison location for periods after 2004. Model runs prior to 2004 will need to use data recorded at a gage located near the City of Coeur d'Alene and may need to be adjusted as a function of flow rates recorded in the Lower Basin. Model scenarios for periods prior to 2004 will have higher degrees of uncertainty associated with the downstream boundary condition. These uncertainties directly affect the model-predicted water surface elevations upstream, specifically for the areas affected by backwater.

  - **Level Logger Datums**: Difficult survey conditions in the Lower Basin result in moderate to high uncertainty in level logger datums (and thus level logger data). Based on the methods used for survey, datum accuracy is estimated to be 2 cm, although it may be greater than 2 cm. More accurate survey is not feasible. Uncertainty is reduced by multiple surveys; however, some logger locations were adjusted between repeat surveys because of individual site circumstances. Logger datums were adjusted based on a best fit line and the assumption of a constant river slope during low flow and high lake level (see Exhibit 16 and the section on Water Level Data for additional discussion of this method). Regardless, moderate uncertainty still exists in level logger data to which the model is calibrated. The adjusted water level data appears reasonable and if errors still exist they are likely less than 2 cm. The effect on model results is therefore relatively minor.
  - **Bank (Lateral Structure) Geometry:** Overbank flows are dependent on the bank geometry, included in the model as lateral structures, and derived from LiDAR. While LiDAR data are generally believed to have high quality, they may inaccurately represent terrain from vegetation and other obstructions. Inaccuracies in the definition of the river banks would translate into inaccurate predictions of the flow exchange over the banks at high flow. Currently, no flow data can be used to validate the model-predicted locations, timing, and magnitude of overbank flooding.
  - **Storage Area Initial Conditions:** Only 6 of the 36 storage areas have level loggers from which to develop initial conditions. Prior to April 14, 2010, none of the storage areas had loggers. Development of storage area initial conditions is limited to assuming conditions and letting the model equilibrate (typically takes less than 1 month of model run time), or to extracting storage area levels from another model run. As long as model runs are started 1 month prior to the period of interest, the uncertainty associated with initial conditions will not affect model results.
  - **Historic Flow Events Are Representative of Flood Events Likely to Occur in the Future:** Future applications of the model will be limited to running the model for historic flow events. This inherently assumes that future flow events are represented by historic flow events. This neglects the effects of climate change and only considers the range of events that have occurred and been recorded in the past.

- Uncertainty related to the calibration process:
  - **Potential for Non-unique Solutions**: The manual and iterative calibration process used for the 1D model, a process that uses limited calibration parameters, gives the impression of a unique model solution when in fact it is not. There are nearly infinite combinations of the values of the calibration parameters (flow roughness factors, tie channel geometry, and adjustments to the tributary inflow hydrographs), many of which could result in model calibration performance as good (or better) than that selected in the final calibrated model. While the combination of calibration parameters selected generate model results that match quite well to recorded data, individual values may not be precisely physically correct because it is not possible to isolate and identify the precisely correct value for each parameter in the model. However, care was taken to make the changes for the right reasons when data existed to support parameter adjustments. For example, tie channel geometry was only adjusted when survey data supported such adjustments, tributary flow were scaled according to the differential in gaged flows into and out of the Lower Basin, and the calibrated flow roughness factors are consistent with the pattern we expected to see (reduced roughness at higher flows).
  - **Calibration and Validation Data Availability:** Calibration data are only available at discreet locations. Calibration of the model is isolated to locations where calibration data is available. Calibration data locations were strategically selected to represent important locations in the model. Validation data are not available for the Braided Geographic Reach; however, the lower three geographic reaches (Dudley, Killarney, and Springston) are considered most important for model calibration and represent the majority of the total modeled river length.

7.0 Future Model Applications

7.1 Advance Understanding of the Conceptual Site Model

The calibrated model can be used to simulate a range of historical flood events to advance current understanding of how the system functions hydraulically over a range of flooding conditions that have occurred in the past and are therefore likely to happen again in the future. This is often referred to as hydraulic characterization and it involves selecting a range of historic flood events (from the period of available data) that reflects the spectrum of flood events that are likely to occur, simulating the existing conditions and summarizing the hydraulic behaviors (flow paths, overbank thresholds, velocities, shear stress, etc.) at multiple scales (local-, reach-, and basin-scale). For the Lower Basin it will be necessary to identify a range of both winter and spring flood events since the characteristics of the floods are so different. Historic flood events can only be selected for the period for which historic flow data exist, which is from 1987 to the present. The list of characterization events may include, but is not limited to, the following historic floods: winter 1996, winter 2011, winter 2012, spring 2008, spring 2011, and spring 2012.

Results from the hydraulic characterization will advance the understanding of the conceptual site model by providing reliable information about how water moves through the Lower Basin, which cannot be obtained through data collection. This effort will indentify basin-scale processes such as the extent of the backwater effect, longitudinal trends in stage, velocity, and shear stress, and flow attenuation affects through the entire basin. At the reach-scale, the model can inform the conditions necessary to cause overbanks flooding, identify flow paths that deliver water and sediment to and from the floodplain, and summarize hydraulic characterizes in all reaches of the Lower Basin.

Results from hydraulic characterization not only advance the understanding of the conceptual site model, they also establish baseline existing conditions to compare against alternative remedial actions.

7.2 Support Data Collection and Data Interpretation

Using flow and lake level forecast data provided by the National Weather Service, the model can be used to forecast river conditions up to 10 days into the future. The river forecast model runs will not be as accurate or reliable as model runs that use historic flow data, because the Northwest Weather Service forecast data are only available for the North Fork and South Fork and the water level of Lake Coeur d'Alene. The forecast model runs will not have Lower Basin tributary flow inputs, but the model results should still provide valuable information about the overall flooding conditions. These river forecast model runs will provide estimates of the following:

- River levels, lake levels, and the flow exchange between the river and lateral lakes.
- When and where overbank flooding will occur.
- Timing of peak flow rates along the entire length of the river system.
- Magnitude of average velocities and shear stresses along the length of the river and how they change over the duration of the event. Results for periods when overbank flooding occurs should be used with caution since model-predicted overbank flooding conditions have not been validated because of the lack of available data.

This information is extremely valuable to data collection planning efforts, which are often designed to sample at targeted times of the flood such as at peak flow. This information can also be used to identify strategic sampling locations. For example, it can be used to identify suspended sediment sampling locations that are designed to measure the concentrations of sediment and lead flowing into lateral lakes and marshes. The model can identify areas where large volumes of water are flowing into lateral lakes and marshes, which would be strategic areas to collect samples. Because flow forecast data are only available 10 days in advance, the information can only be used to refine sample locations and the exact timing of crew deployments. Sampling plans still need to be developed well in advance.

Following a flood event, the model can be used to help interpret data collected during the flood. Data provide valuable information that documents what occurred during the flood (such as sediment and lead concentrations), but data alone cannot explain why they occurred. For example, a suspended sediment sample collected at multiple points along the length of river may show a distinct pattern or trend, such as increasing or decreasing concentrations. The model can be used to investigate why the observed patterns exist. Observed patterns in suspended sediment data can be correlated with trends in hydraulic conditions (flow, velocity, and shear stress) predicted by the model. Being able to explain why trends in the measured data exist will help advance understanding about how the system functions, which will strengthen the conceptual site model. Post-flood model simulation will be more reliable than the forecasted model runs because they will include measured inflows from the upper basin, measured water levels at Lake Coeur d'Alene, and estimates of Lower Basin tributary inflows.

7.3 Evaluate Remedial Action Alternatives

The 1D hydraulic model provides coarse-scale hydraulic results that can both inform the development of remedial action alternatives and quantify hydraulic impacts associated with each respective alternative action, which will be evaluated with respect to the baseline conditions described in Section 7.1. The flood events used to evaluate alternative remedial actions will be the same as those used to characterize the existing system, so the impacts can be directly compared. Although the 1D model cannot produce hydraulic results in as much detail as the 2D model or simulate sediment transport processes, it can reliably predict impacts to flow rates, water surface elevations, and average velocities and shear stresses in the main channel. Also, because the 1D model can be applied more quickly and efficiently compared to the 2D models, it can be used to screen the preliminary remedial action concepts. Through this process, results from the 1D model can be used to identify remedial actions that are deemed to have fatal flaws and help refine those that appear to meet the desired objective. Using the 1D as a preliminary screening tool will make the 2D modeling effort more efficient and effective.

7.4 Guide Design of Remedial and Restoration Actions

Once effective remedial actions have been identified, they will need to be advanced from a concept level to a detailed level so that final design documents can be prepared. The 1D model can be used to provide some of the hydraulic information that will be necessary to develop detailed final design documents. The 2D models will likely provide higher resolution and more reliable hydraulic information to guide the final design process, but the 1D model can used early in the process to help refine the concept and help focus the 2D modeling effort.

The 1D model can also be used in the same way to guide design of restoration actions.

8.0 Conclusions

The 1D hydraulic model for the Lower Basin is fully developed, calibrated, and successfully validated. Results from the calibration and validation process have highlighted both the strengths and limitations of the 1D model. The 1D model is most well-suited for predicting water surface elevations and routing the flood wave. The model appears to be routing water to and from the floodplain at the correct time and location. The magnitude of the flow delivered to the floodplain at high river stages is greater than expected and this has not yet been validated. The routing of flows through the floodplain is a process that will be more accurately represented by the 2D hydraulic model. The model has been calibrated to both winter and spring flooding events and has a similar level of reliability for both types of flood events, although it performs better for spring flooding events, which are less flashy.

The 1D model can now be used to support continued advancement of the conceptual site model, guide flood-stage data collection efforts, evaluate the coarse-scale hydraulic impacts of alternative remedial actions, and guide development and design of selected remedial actions.

The 1D hydraulic model is only one component of the simulation model; the 2D hydraulic model is under development and scheduled for completion in the fall of 2013. The 2D model will provide a higher level of detail and represent the complex floodplain flows more accurately. These models are complimentary—the 1D model can be applied quickly but only provides coarse-scale hydraulic results, the 2D model requires longer simulation times but provides more accurate and detailed results. The 1D model will be used to guide development of the 2D model and help focus future applications of the 2D model.

9.0 References

Avista Corporation. 2003. Coeur d'Alene River hydro-acoustic bathymetric survey.

Berenbrock, C. and A. Tranmer. 2008. *Simulation of Flow, Sediment Transport, and Sediment Mobility of the Lower Coeur d'Alene River, Idaho*. Scientific Investigations Report 2008–5093. U.S. Geological Survey. Reston, Virginia.

Black, J. 2003. *Vertical Reference Datums in Use on Coeur d'Alene River, Idaho 7683-17.* Memorandum. Hart Crowser, Inc. Seattle, Washington. October 10.

Bookstrom, A.A., S.E. Box, B.L. Jackson, T.R. Brandt, P.D. Derkey, and S.R. Munts. 1999. *Digital Map of Surficial Geology, Wetlands, and Deepwater Habitats, Coeur d'Alene River Valley, Idaho.* U.S. Geological Survey Open-File Report OF 99-548.

Cowardin, L. M., V. Carter, F. C. Golet and E. T. LaRoe. 1979. *Classification of wetlands and deepwater habitats of the United States*. U.S. Department of the Interior, Fish and Wildlife Service, Washington D.C. 131pp.

CH2M HILL. 2000. *Draft Final Conceptual Site Model Summary and Update*. Prepared for U.S. Environmental Protection Agency.

CH2M HILL. 2010a. *Enhanced Conceptual Site Model for the Lower Basin of the Coeur d'Alene River, Synopsis*. Prepared for U.S. Environmental Protection Agency. August.

CH2M HILL. 2010b. *Enhanced Conceptual Site Model for the Lower Basin of the Coeur d'Alene River, Technical Memorandum H – Model Evaluation and Recommendation*. Prepared for U.S. Environmental Protection Agency. August.

CH2M HILL. 2011. *Modeling Work Plan: Lower Basin of the Coeur d'Alene River (OU3)*. Draft Technical Memorandum. Prepared for U.S. Environmental Protection Agency. April 2011.

CH2M HILL. 2013. Hydrologic Model Technical Memorandum [working draft]

Chow, V.T. 1959. Open-Channel Hydraulics. McGraw-Hill Book Company, NY.

U.S. Army Corps of Engineers (USACE). 2010a. *HEC-RAS River Analysis System Hydraulic Reference Manual Version 4.1*. January 2010.

U.S. Army Corps of Engineers (USACE). 2010b. *HEC-RAS River Analysis System Users Manual Version 4.1*. January 2010.

U.S. Geological Survey (USGS). 1990. *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains*. Water Supply Paper 2339.

U.S. Environmental Protection Agency (EPA). 2001. *Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study*. Prepared for U.S. Environmental Protection Agency by URS Greiner, Inc., and CH2M HILL. September.

U.S. Environmental Protection Agency (EPA). 2002. *The Bunker Hill Mining and Metallurgical Complex, Operable Unit 3 Record of Decision*. September.

Van Rijn, L.C. 1984. *Sediment transport, part I: bed load transport*. Journal of Hydraulic Engineering. Volume 110, issue 10. pp 1431-1456.

Exhibits

Exhibits

b. River/Lake Exchange

-*v*. WY 2012 (Validation)

a. River and Lake Logger Residual

b. River/Lake Exchange

37 Swan Lake Residual and Exchange

-*c*. WY 2011 (Calibration)

a. River and Lake Logger Residual

b. River/Lake Exchange

-*v*. WY 2012 (Validation)

a. River and Lake Logger Residual

b. River/Lake Exchange

38 Medicine and Cave Lake Residual and Exchange

-*c*. WY 2011 (Calibration)

a. River and Lake Logger Residual

b. Cave Lake Exchange with Medicine Lake

c. Cave Lake Exchange with River

d. Medicine Lake Exchange with River

-*v*. WY 2012 (Validation)

a. River and Lake Logger Residual

b. Cave Lake Exchange with Medicine Lake

c. Cave Lake Exchange with River

d. Medicine Lake Exchange with River

39 Killarney Lake Residual and Exchange

-*c*. WY 2011 (Calibration)

a. River and Lake Logger Residual

b. River/Lake Exchange

-*v*. WY 2012 (Validation)

a. River and Lake Logger Residual

b. River/Lake Exchange

40 Black Rock River Logger Residual

-*c*. WY 2011 (Calibration)

-*v*. WY 2012 (Validation)

41 Dudley River Logger Residual

-*c*. WY 2011 (Calibration)

-*v*. WY 2012 (Validation)

42 Below Bull Run River Logger Residual –*c.* WY2012 (Calibration)

43 Above Bull Run River Logger Residual –*c.* WY2012 (Calibration)

44 Dredge Pool River Logger Residual –*c.* WY2012 (Calibration)

45 Confluence River Logger Residual –*c.* WY2012 (Calibration)

46 River Gage Calibration Residual-Duration

-*c*. WY 2011 & WY2012 (Calibration)

a-g. Individual River Gages (WY 2011)

h-k. Individual River Gages (WY 2012)

l. All River Gages – Entire Calibration Period

m. All River Gages – Spring Calibration Events

n. All River Gages – Winter Calibration Events

-*v*. WY 2012 (Validation)

a-g. Individual River Gages

h. All River Gages – Entire Calibration Period

i. All River Gages – Spring Calibration Events

j. All River Gages – Winter Calibration Events

47 River Gage Calibration Absolute Residual-Duration

-*c*. WY 2011 & WY2012 (Calibration)

a-g. Individual River Gages (WY 2011)

h-k. Individual River Gages (WY 2012)

l. H: All River Gages – Entire Calibration Period

m. I: All River Gages – Spring Calibration Events

n. J: All River Gages – Winter Calibration Events

-*v*. WY 2012 (Validation)

a-g. Individual River Gages

h. All River Gages – Entire Calibration Period

i. All River Gages – Spring Calibration Events

j. All River Gages – Winter Calibration Events

48 Lake Gage Calibration Residual-Duration\

-*c*. WY 2011 (Calibration)

a-f: Individual Lake Gages

g. All Lake Gages – Entire Calibration Period

h. All Lake Gages – Spring Calibration Events

i. All Lake Gages – Winter Calibration Events

-*v*. WY 2012 (Validation)

a-f: Individual Lake Gages

g. All Lake Gages – Entire Calibration Period

h. All Lake Gages – Spring Calibration Events

i. All Lake Gages – Winter Calibration Events

49 Individual Lake Gage Calibration – Absolute residual-duration

-*c*. WY 2011 (Calibration)

a-f: Individual Lake Gages

g. All Lake Gages – Entire Calibration Period

h. All Lake Gages – Spring Calibration Events

i. All Lake Gages – Winter Calibration Events

-*v*. WY 2012 (Validation)

a-f: Individual Lake Gages

g. All Lake Gages – Entire Calibration Period

h. All Lake Gages – Spring Calibration Events

i. All Lake Gages – Winter Calibration Events

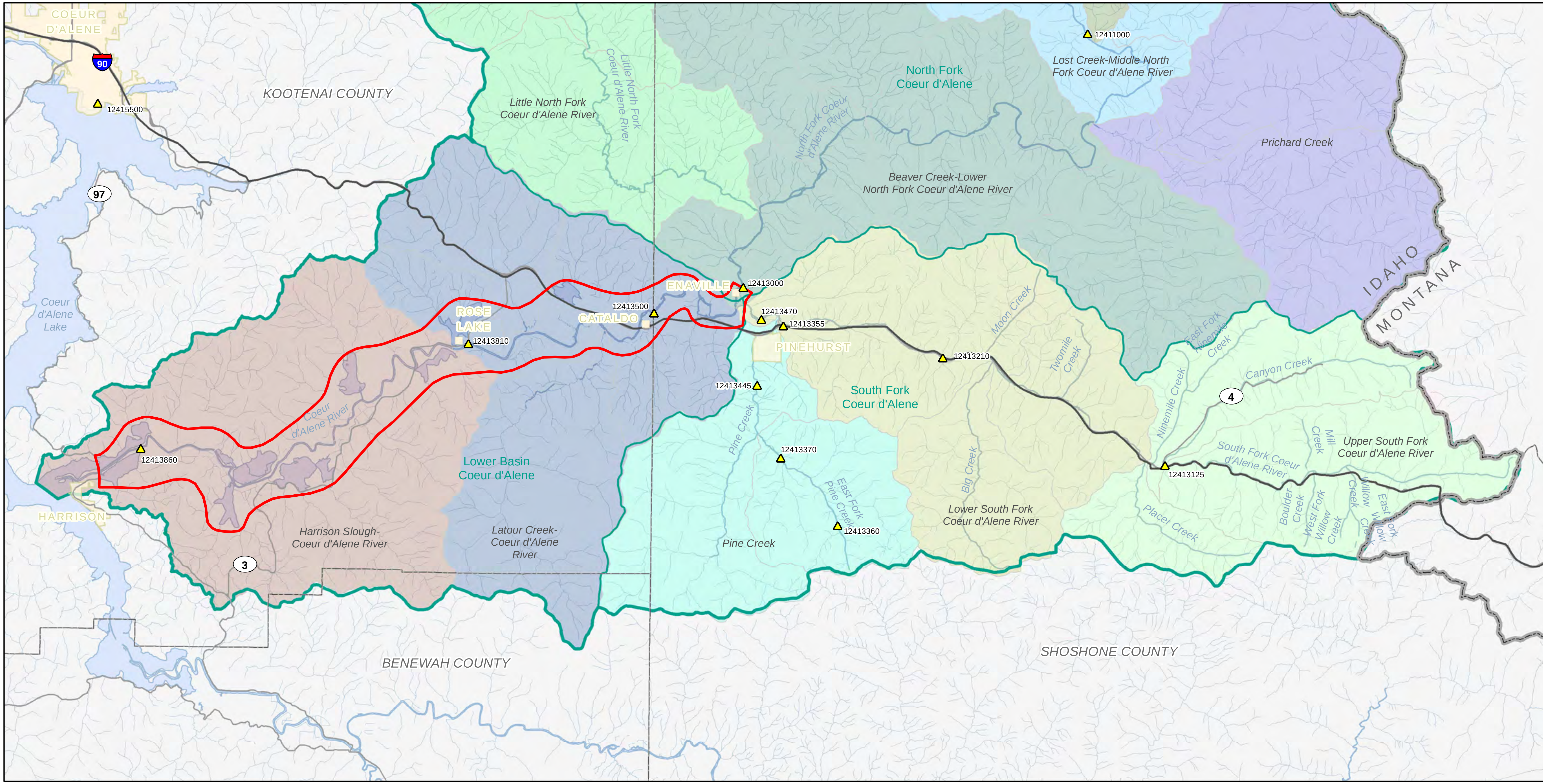
50 Table of Residual Statistics

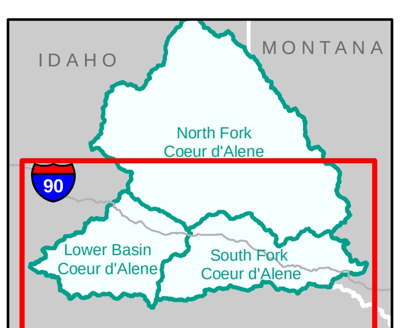
a. Flow Residual Statistics

b. Water Surface Elevation Residual Statistics

51 Table of Sensitivity Analysis Summary

52 Floodplain Flow Rates and Paths





USGS Gage (Gage Number)
Defined Hydraulic Model Domain
Interstate Highway
Local Highway
City Limit
Coeur d'Alene Basin Hydrologic Boundary
4th Field HUC
5th Field HUC
6th Field HUC

Source: USGS (4th Level HUC); IDWR (5th & 6th Level HUC, USGS Gages); NHDPlus (Rivers, Waterbodies); ESRI base data (Interstates 2006, Major Highways 2008).

0 1 2 4 Miles

Exhibit 1. **Overview Map**
Model Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River

CH2MHILL

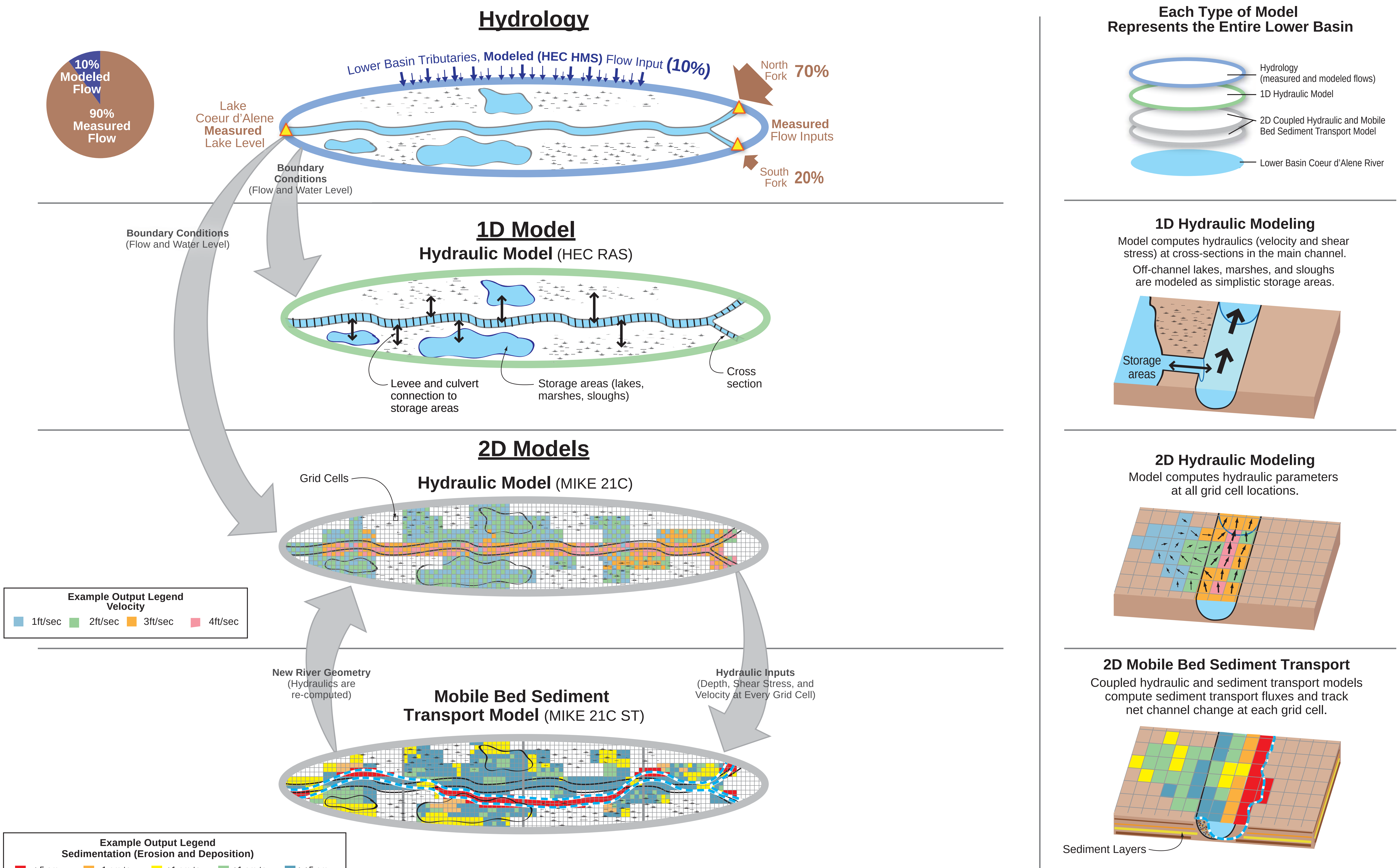


Exhibit 2. Lower Basin Coeur d'Alene River Simulation Model Components

Legend	HEC-RAS Term	Used to Simulate:
1262-Medicine3	Storage Area	Lateral lakes, ponds, marshes
	Lateral Structure	Levees; overbank terrain controlling exchange between river and floodplain
17211.12	Cross Section	Channel geometry
	River Centerline	Represents location of channel; not actually used for simulation
1277	Storage Area Connection	Like Lateral Structures, but simulates exchange between storage areas.

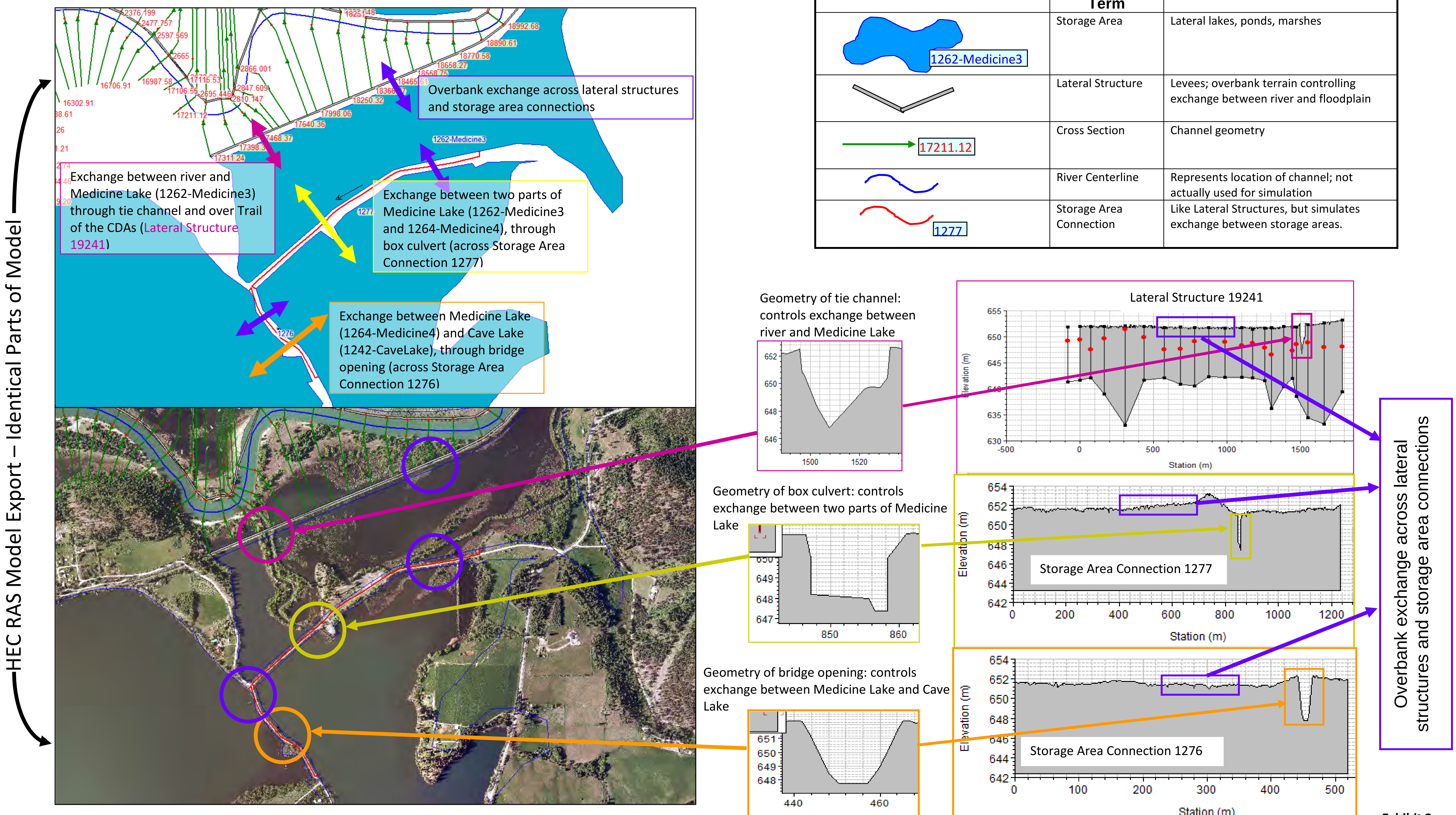


Exhibit 3
Quasi-2D Model Set-up
Model Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

EXHIBIT 4. MODEL UNITS
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

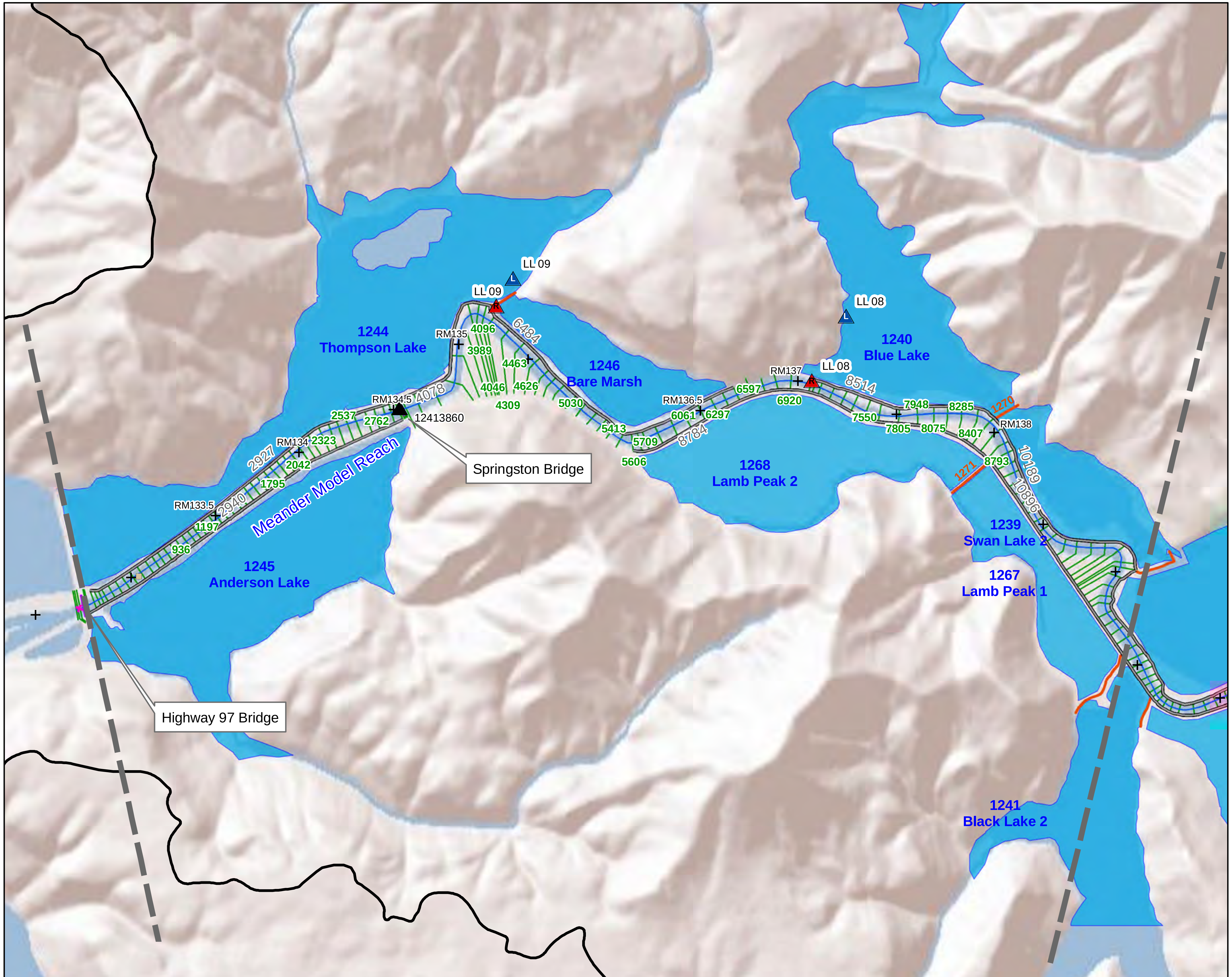
Element	Unit	Model Application
Distance	meter (m)	Cross section geometry, lateral structure geometry, culvert diameter, storage area connection geometry
Flow	cubic meters per second (cms)	Input flow boundary conditions, flow results
Elevation	meter (m)	Input downstream lake level boundary condition, model water surface elevation results
Area	square meters (m^2)	Cross section area
Volume	cubic meters (m^3) or 1,000's of cubic meters (1,000 m^3)	Storage area elevation-volume curve

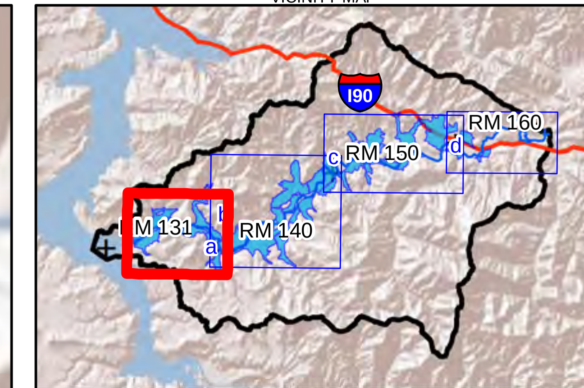
EXHIBIT 5. TABLE OF DTM DATA SOURCES
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

File Name	Original Source	Date	Type	Method	Firm
20120110_p5m_EGS_Edited.las	Gravity_0_5m_Gridded_Mean.txt	20120110	Bathymetry	Multi-Beam	Gravity/EGS
	Gravity_0_5_mean_gridded.txt (Different File than Above)	20120208			Gravity/EGS
all_xyz.las	all_xyz.txt	20110828	Bathymetry	Rod and Single Beam	Solmar
CH2MHill_Coeur d'Alene Bathymetry_Braided Reach_UTM-N-11-meters_NAVD88-meters.las	(same name .xyz extension)	20110715	Bathymetry		NWHydro
Working_DTM.dgn Layer(75): 2010_david_mills_bathy DTM		2010	Bathymetry	Rod and Single Beam	Critigen
Working_DTM.dgn Layer(77): Ducks_unlimited DTM			Topo Survey		CH2M HILL
Working_DTM.dgn Layer(70): Gravity 091511 rod shots DTM		2011	Bathymetry	Rod	Gravity
Working_DTM.dgn Layer(71): Gravity 10-02-2011 single beam DTM		2011	Bathymetry	Single Beam	Gravity
Working_DTM.dgn Layer(52): VA_DTM_BRKL		2011	Edits only	Connecting breakline	Critigen

EXHIBIT 5. TABLE OF DTM DATA SOURCES
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

File Name	Original Source	Date	Type	Method	Firm
Working_DTM.dgn Layer(54): BREAKLINES FABRICATED DTM		2012	Edits only	Connecting breakline	Critigen
Working_DTM.dgn Layer(74): 2004 _Lake_bathy_contours DTM		2004			
Working_DTM.dgn Layer(55): Critigen 2010 Rod Shots DTM		2010	Bathy and land	Rod	Critigen
Various files, not all unthinned files were used to make these	15,112,979 Points above Elevation 680 meters		Lidar		USGS(?)





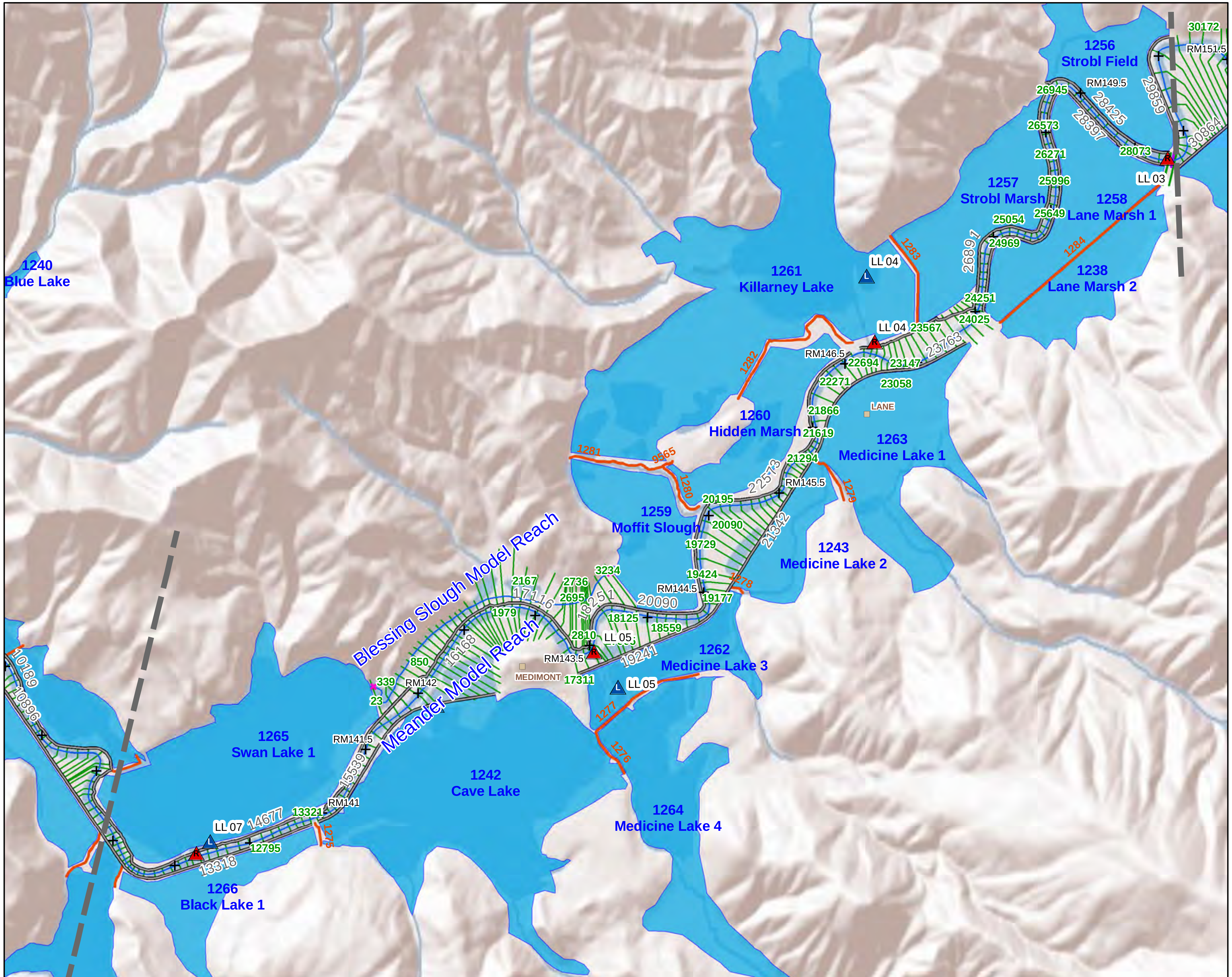
LEGEND

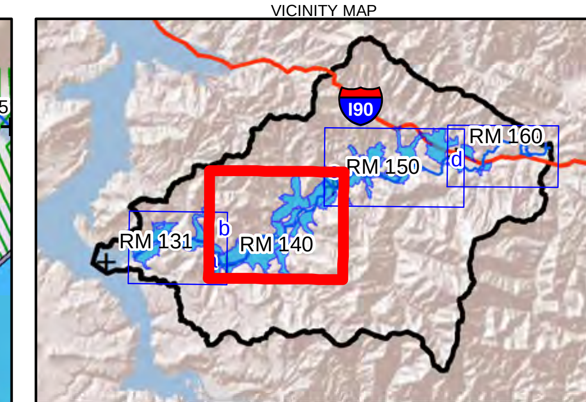
- Cities
- Lake Level Logger
- River Level Logger
- USGS Gage
- RiverMile
- Lower Basin Boundary
- Bridges
- Model Reach
- LateralStructures
- Storage Area Connections
- Model Cross Sections
- StorageAreas
- Highways
- Geographic Reach

N

0 1 2 3
Kilometers

Exhibit 6. a
Model Network -
Springston Geographic Reach
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)





LEGEND

- Cities
- Lake Level Logger
- River Level Logger
- USGS Gage
- RiverMile
- Lower Basin Boundary
- Bridges
- Model Reach
- LateralStructures
- Storage Area Connections
- Model Cross Sections
- StorageAreas
- Highways
- Geographic Reach

N

0 1 2 3

Kilometers

Exhibit 6. b
Model Network -
Killarney Geographic Reach
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

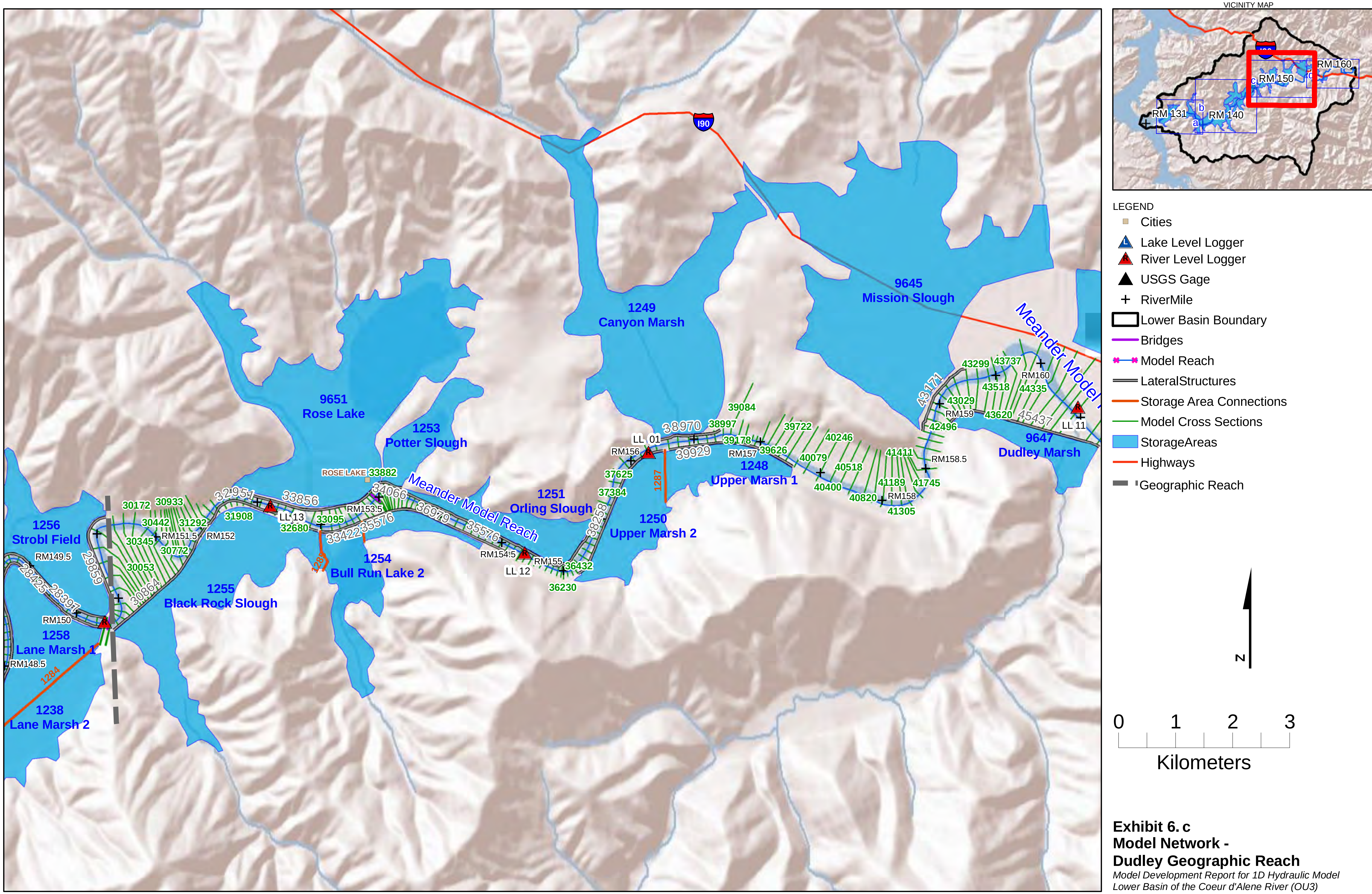


Exhibit 6.c
Model Network -
Dudley Geographic Reach
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

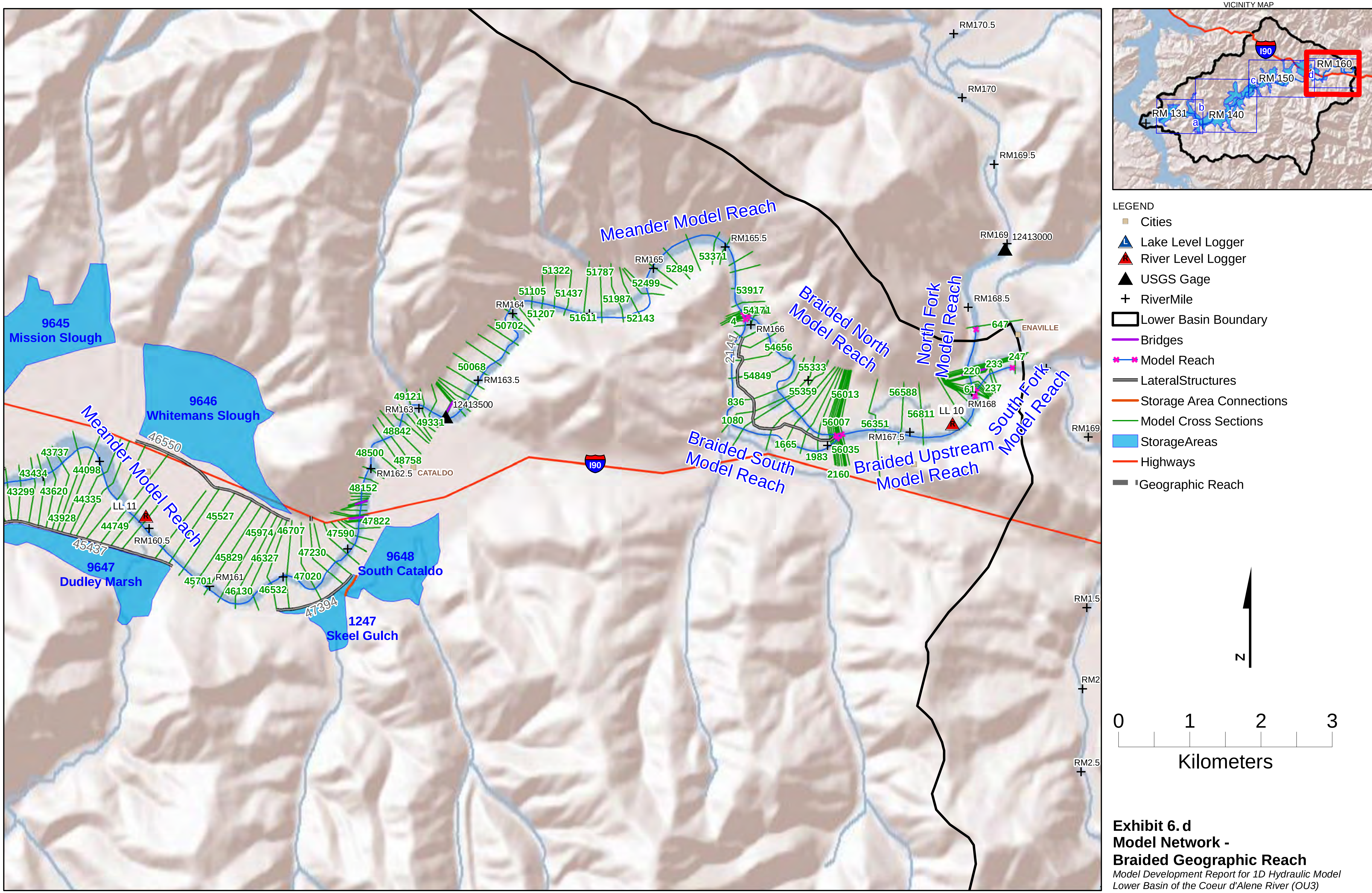
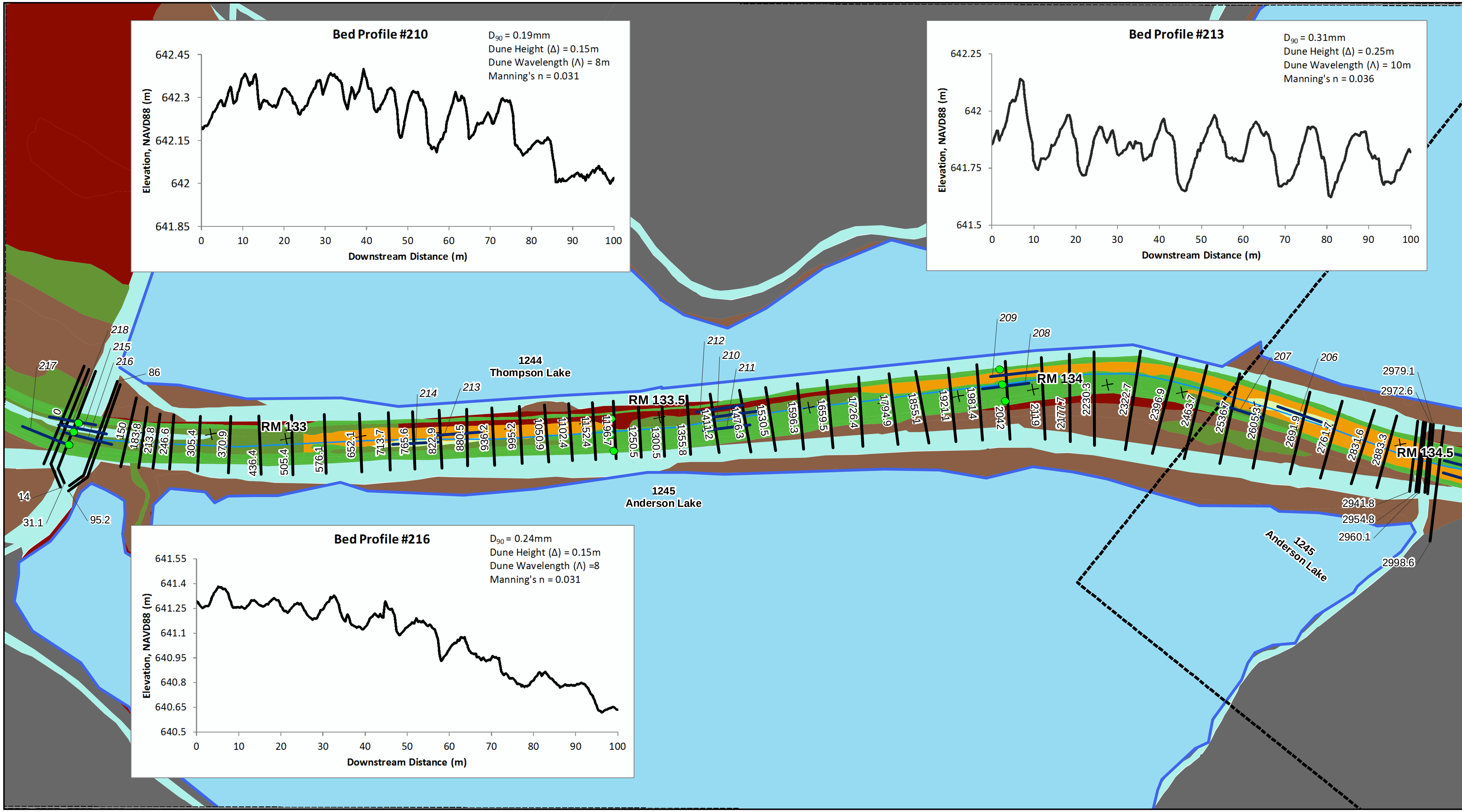
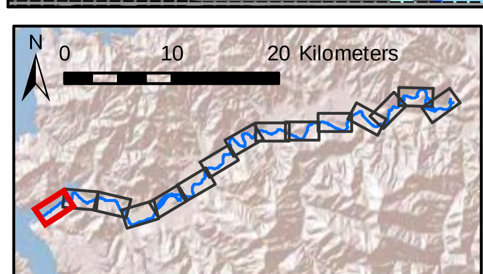


Exhibit 6. d
Model Network -
Braided Geographic Reach
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

EXHIBIT 7. MODELING REACH SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Model Reach Name	River	River Miles	Length (km)	Upstream Junction	Downstream Junction
Meander	Coeur d'Alene	132.7 – 165.8	49.1	Meander Start	Not applicable
Blessing Slough	Blessing Slough	141.7 – 143.9	3.4	1259-MoffitSloug	1265-SwanLake1
Braided South	Coeur d'Alene	165.9 – 167.0	2.2	Braided Split	Meander Start
Braided North	Coeur d'Alene	165.9 – 167.0	2.1	Braided Split	Meander Start
Braided Upstream	Coeur d'Alene	167.1 – 167.9	1.5	Confluence	Braided Split
North Fork	North Fork Coeur d'Alene	168.0 – 168.4	0.6	Not applicable	Confluence
South Fork	South Fork Coeur d'Alene	168.0 – 168.3	0.5	Not applicable	Confluence





Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value	
0.016 - 0.019	0.040 - 0.044
0.020 - 0.024	0.045 - 0.049
0.025 - 0.029	0.050 - 0.075
0.030 - 0.034	0.076 - 0.100
0.035 - 0.039	> 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

0 100 200 Meters

Exhibit 8.a
Channel and Floodplain Roughness
RM 132.7 - RM 134.6
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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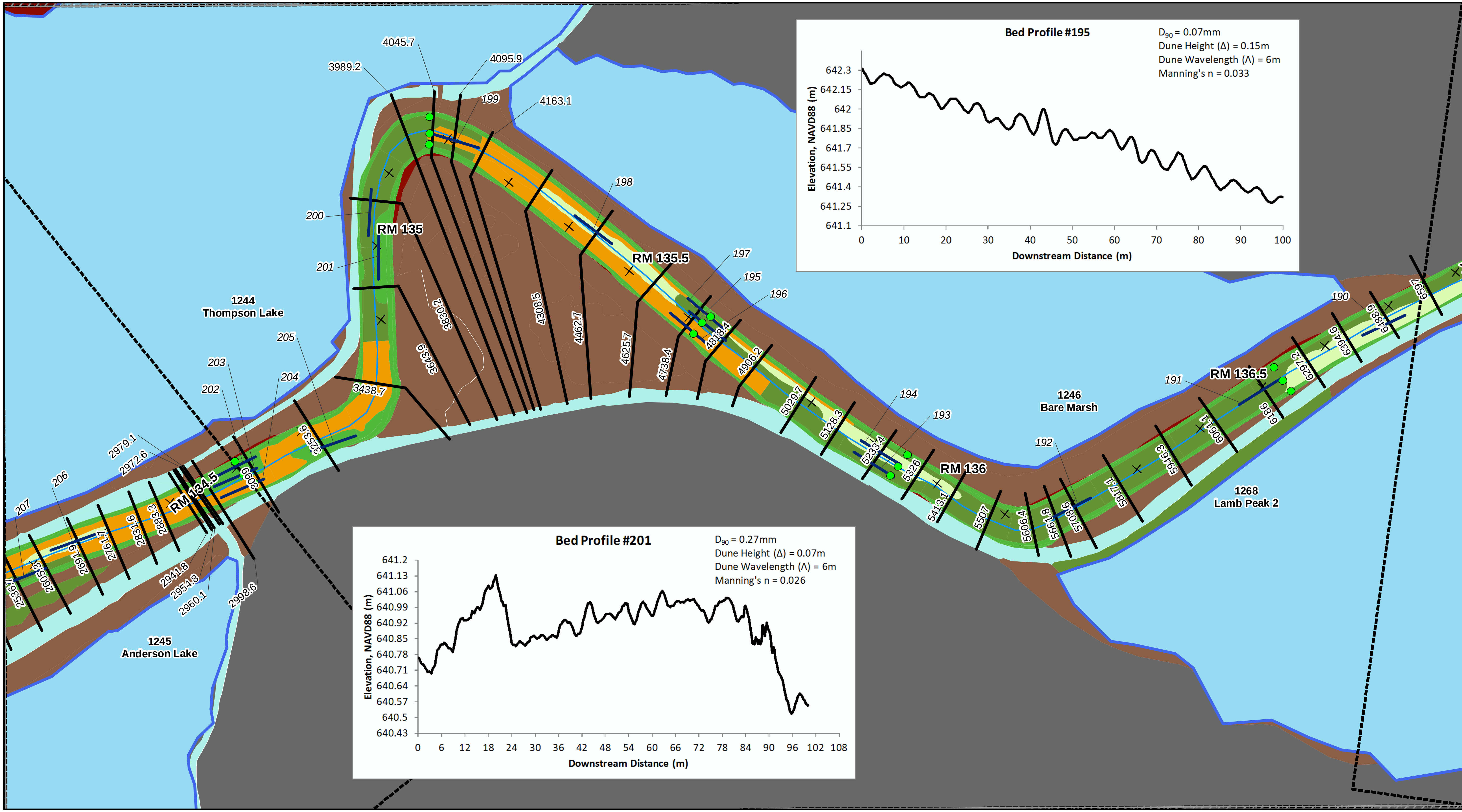

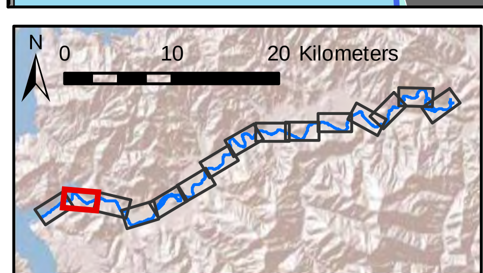

Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

N

0 100 200 Meters

Exhibit 8.b
Channel and Floodplain Roughness
RM 134.3 - RM 136.8
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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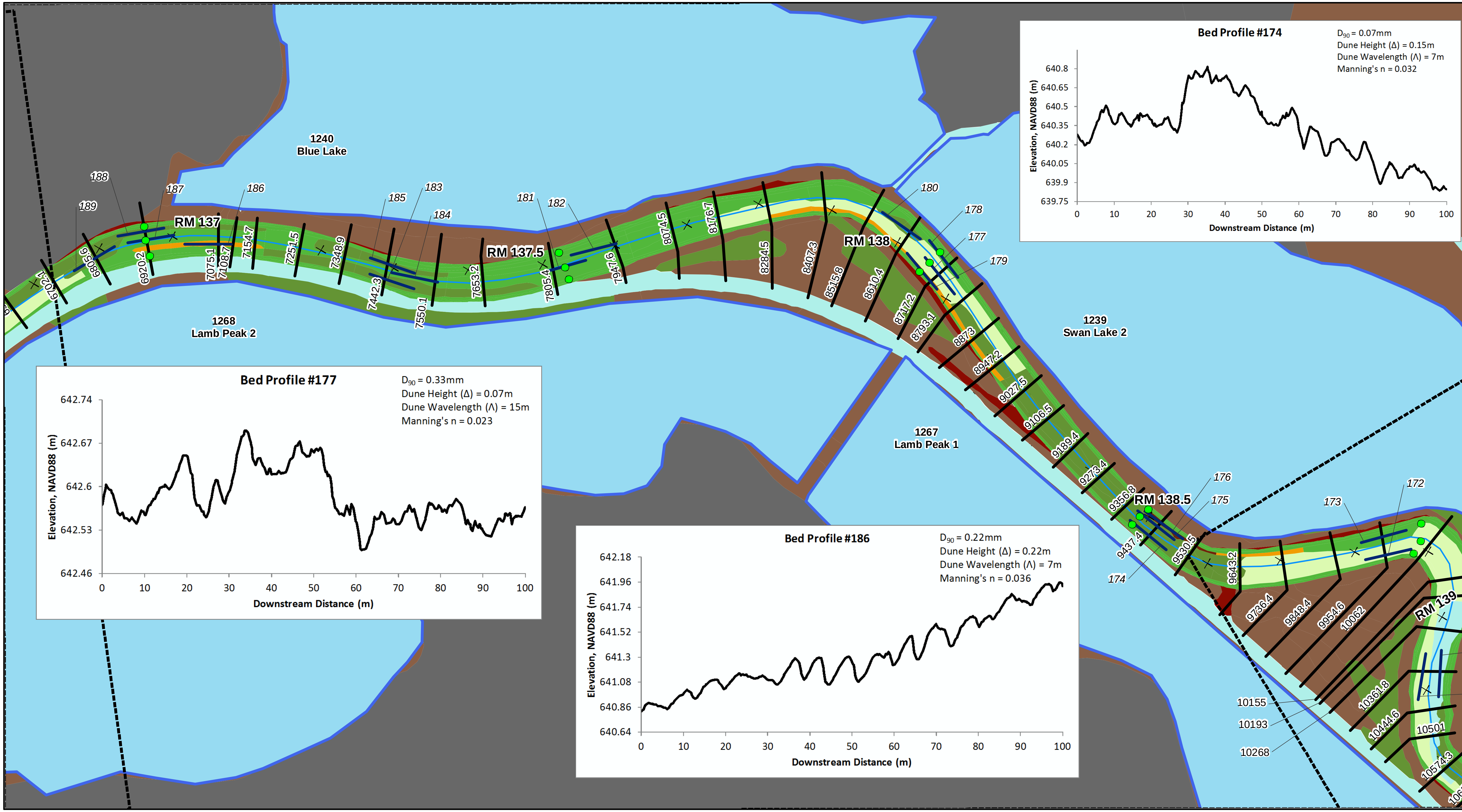

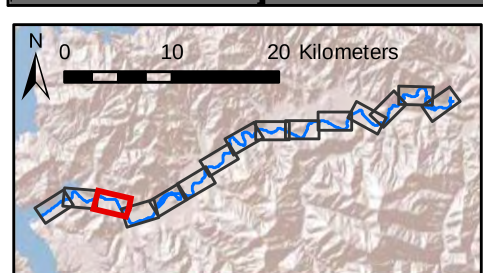

Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

N

0 100 200 Meters

Exhibit 8.c
Channel and Floodplain Roughness
RM 136.8 - RM 139.2
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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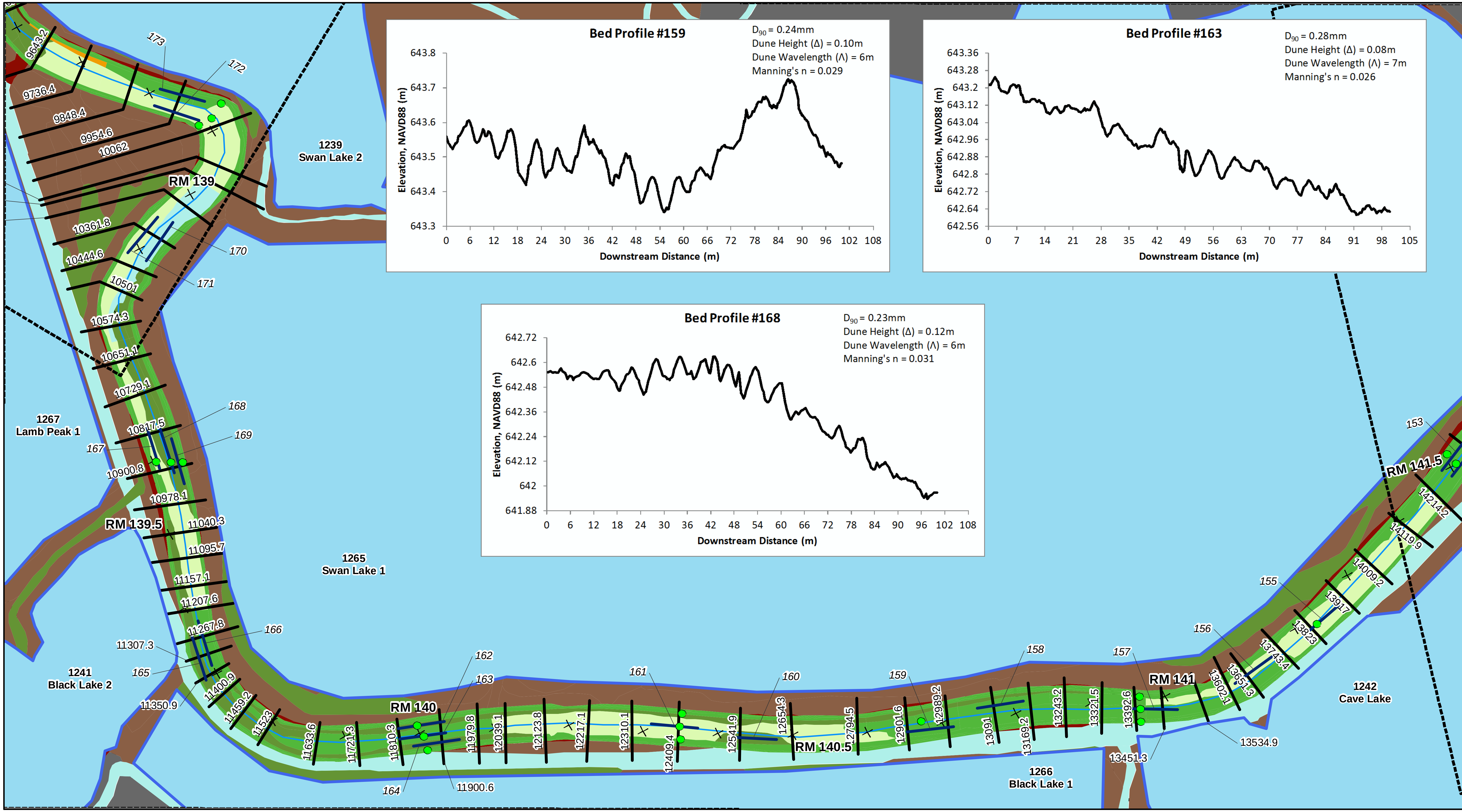
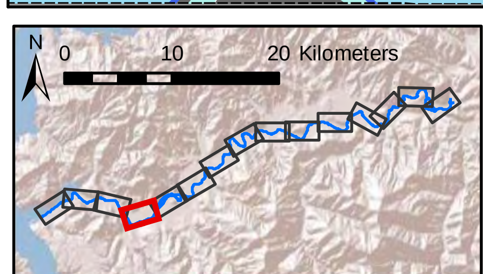




Legend

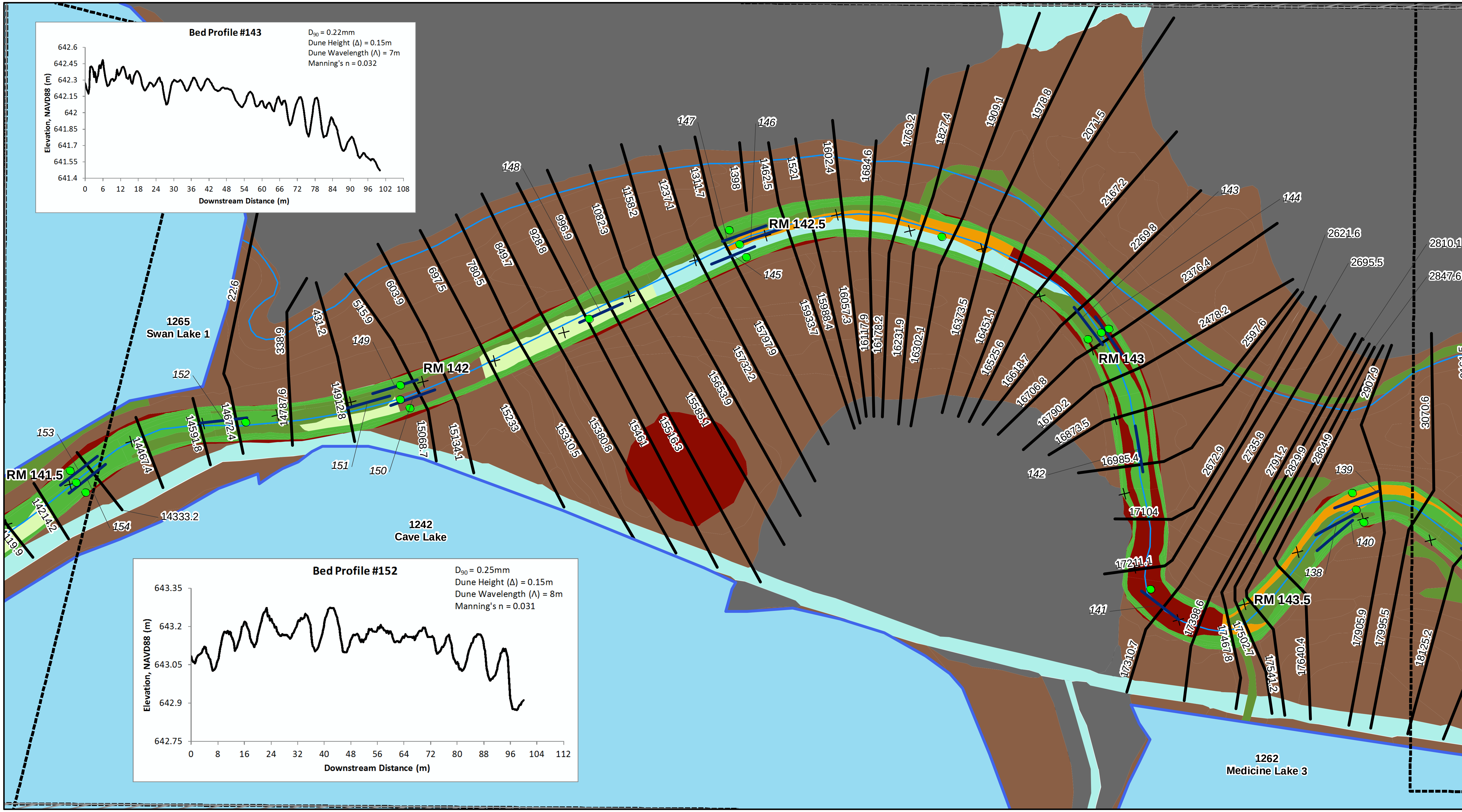
- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

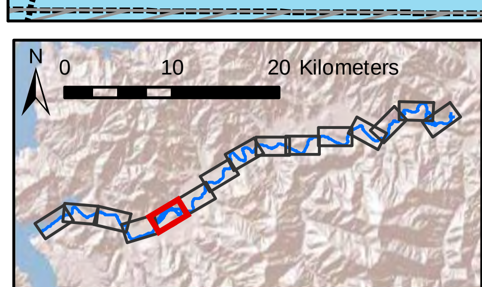
Manning's n Value

- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

Exhibit 8.d
Channel and Floodplain Roughness
RM 138.6 - RM 141.5
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)





Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

0.016 - 0.019	0.040 - 0.044
0.020 - 0.024	0.045 - 0.049
0.025 - 0.029	0.050 - 0.075
0.030 - 0.034	0.076 - 0.100
0.035 - 0.039	> 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

0 100 200 Meters

Exhibit 8.e
Channel and Floodplain Roughness
RM 141.4 - RM 143.8
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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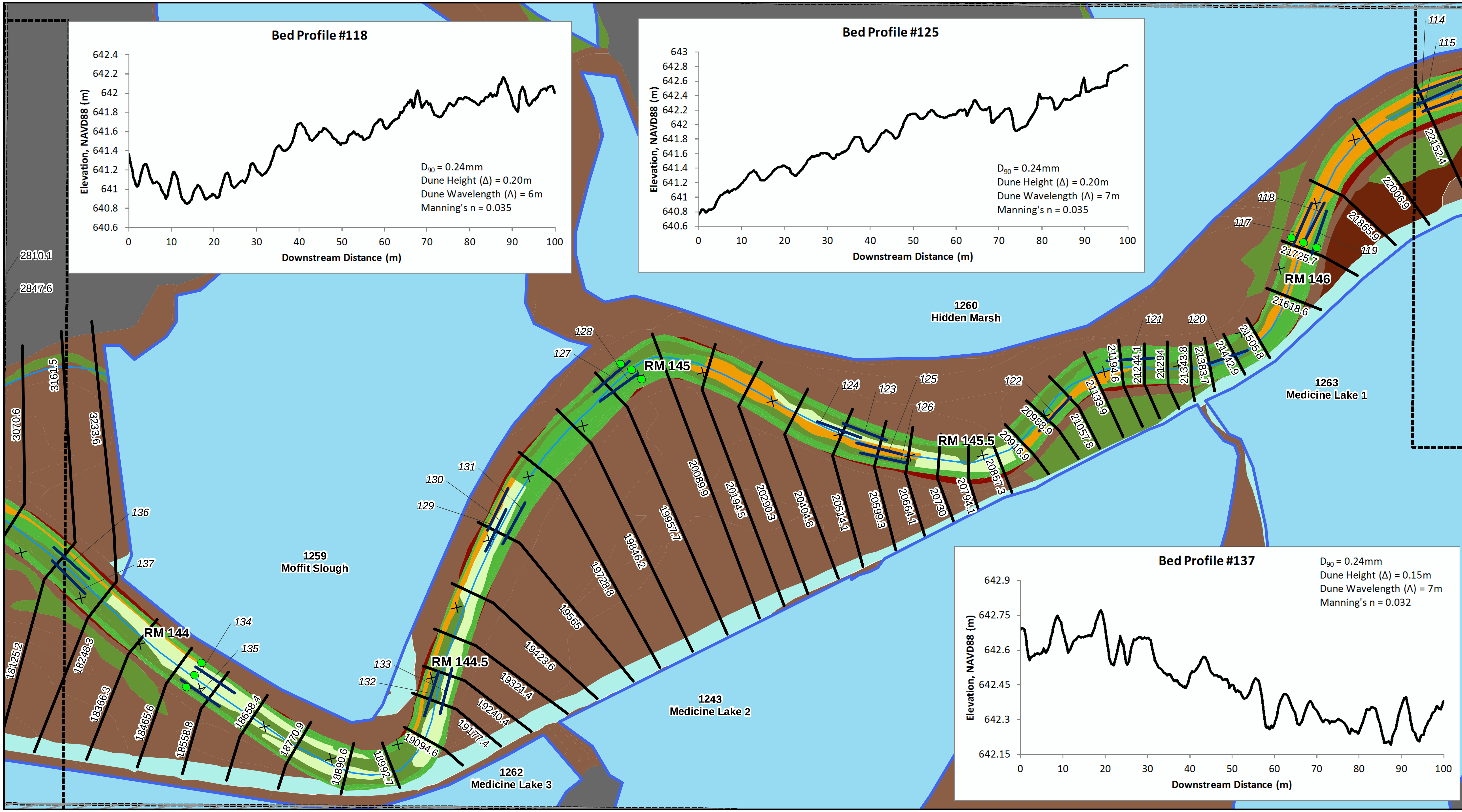

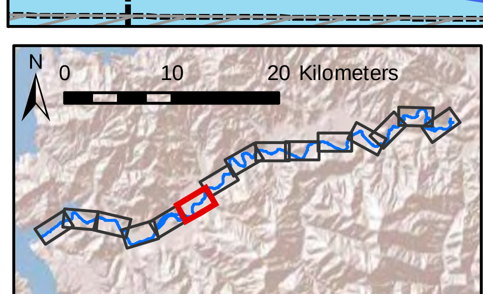

Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

Notes:

1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

0 100 200 Meters

Exhibit 8.f
Channel and Floodplain Roughness
RM 143.8 - RM 146.3
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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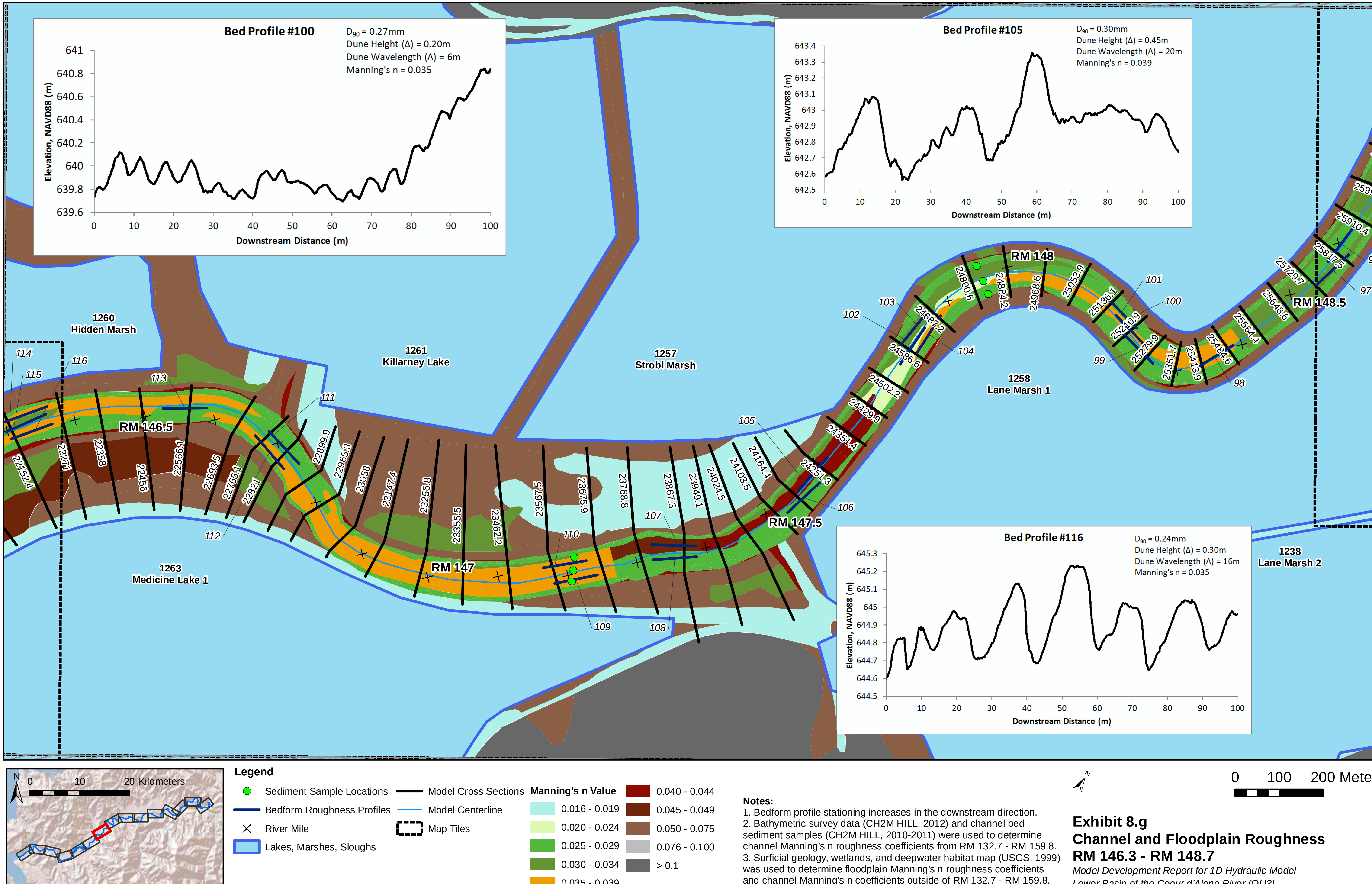

Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

Exhibit 8.g
Channel and Floodplain Roughness
RM 146.3 - RM 148.7
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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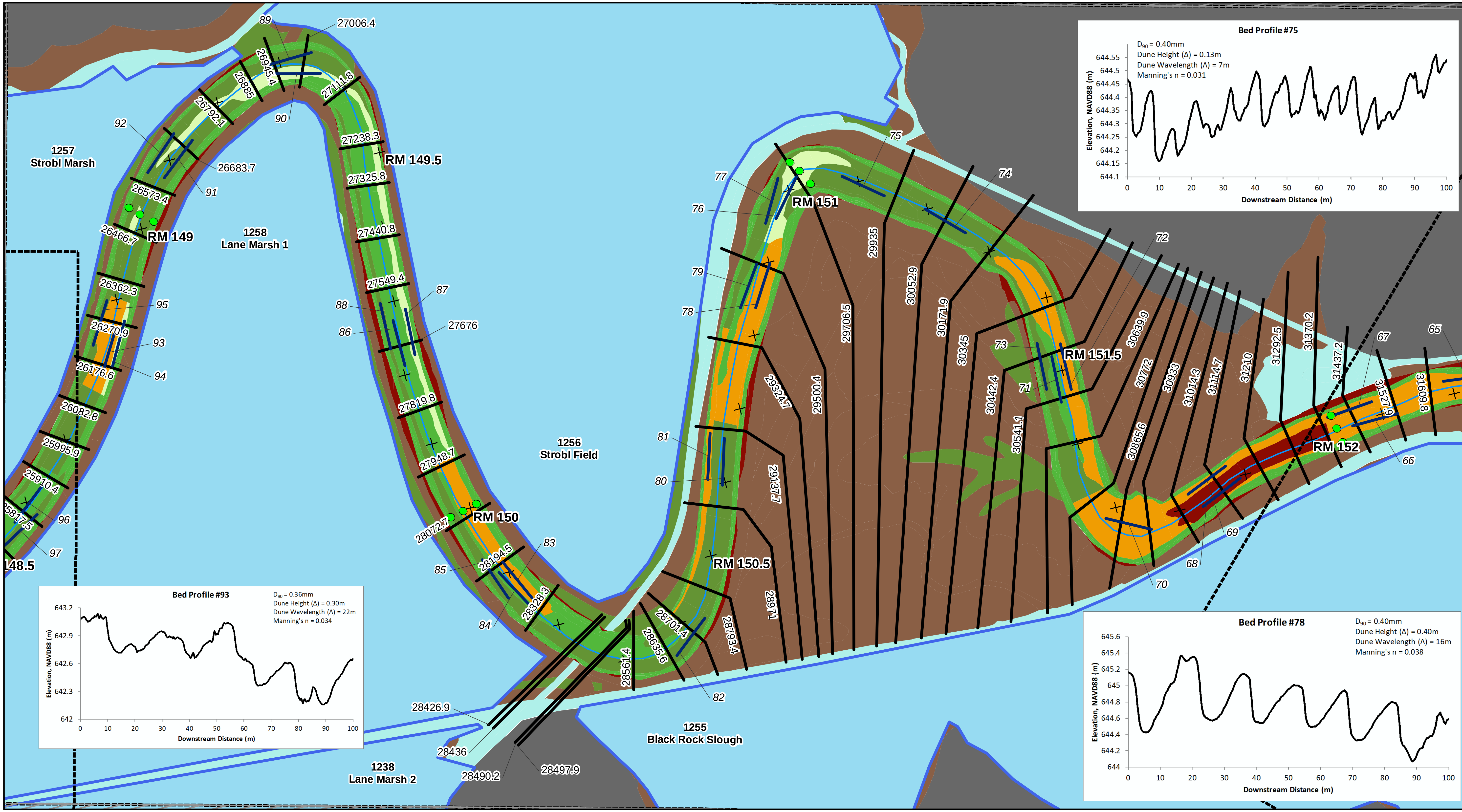

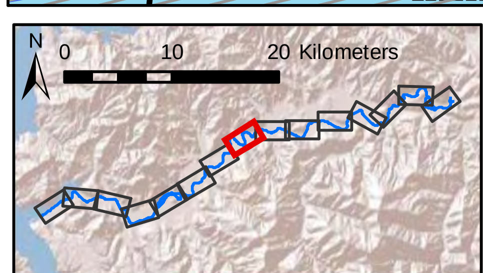

Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

0 100 200 Meters

Exhibit 8.h
Channel and Floodplain Roughness
RM 148.6 - RM 152.2
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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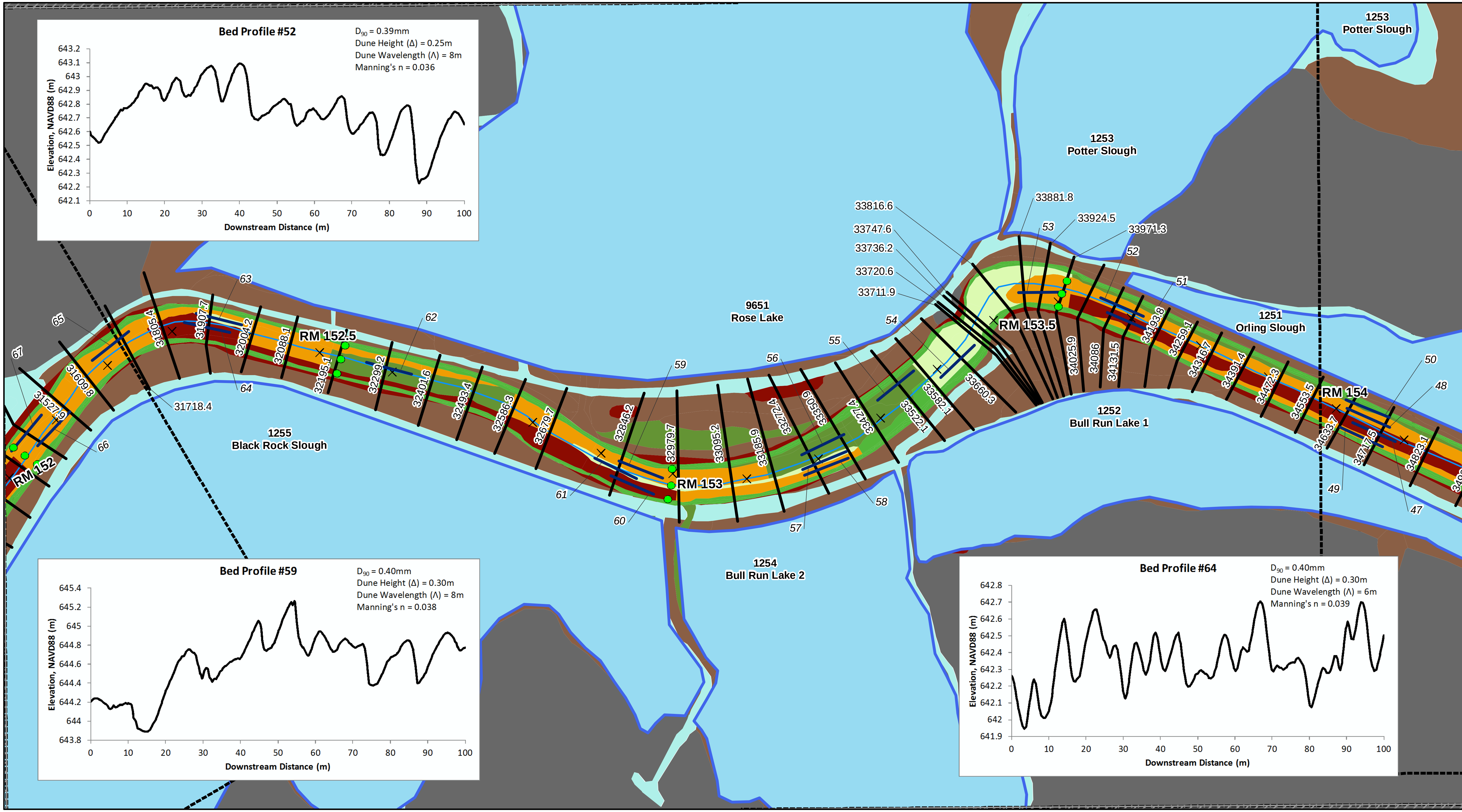
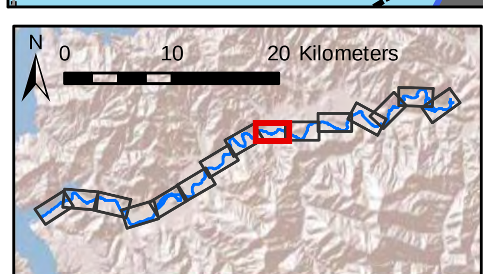




Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

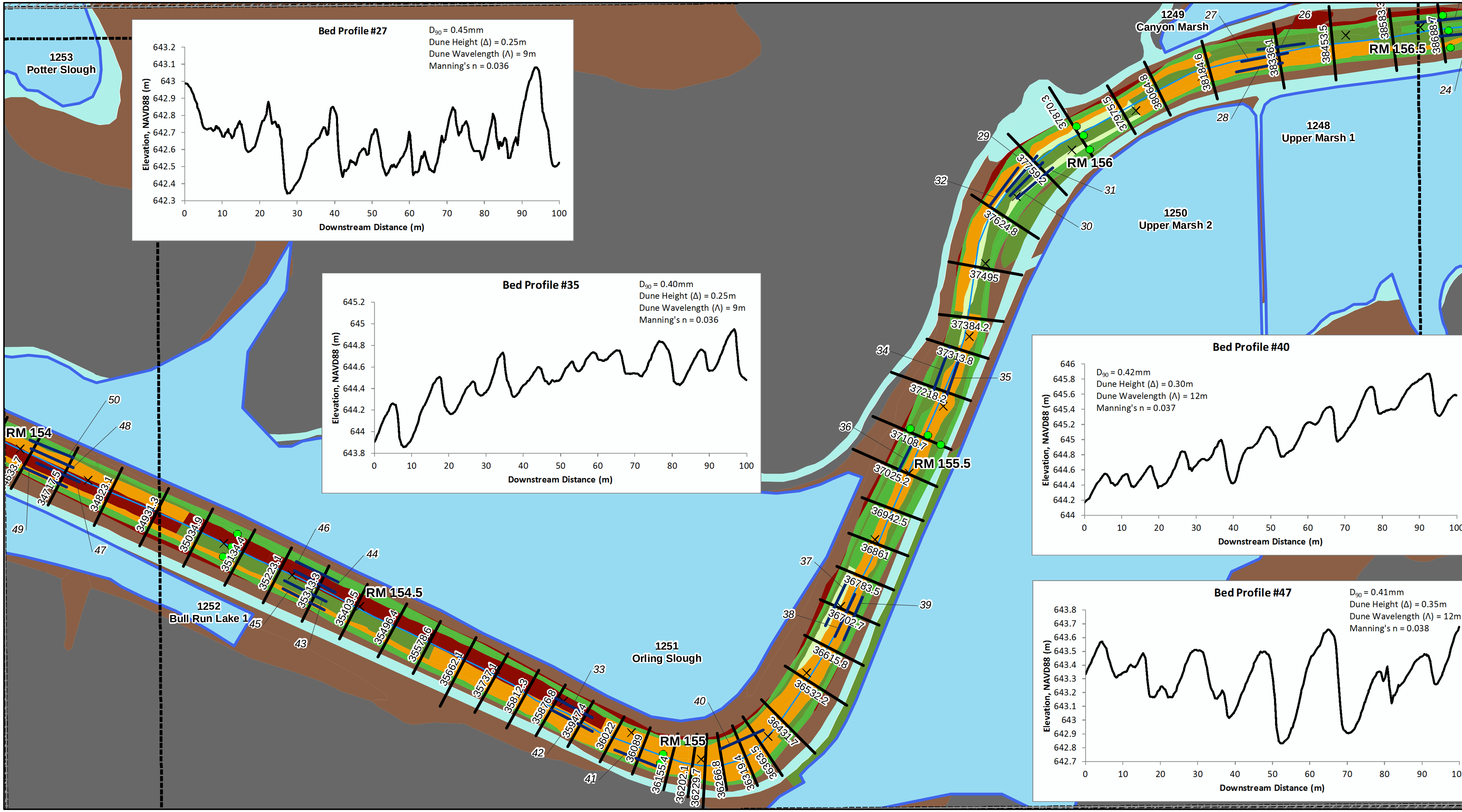
- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

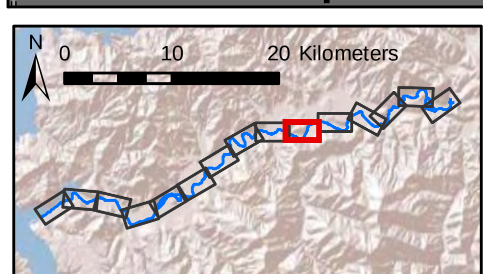
N

0 100 200 Meters

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

Exhibit 8.i
Channel and Floodplain Roughness
RM 152.0 - RM 154.2
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)





Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

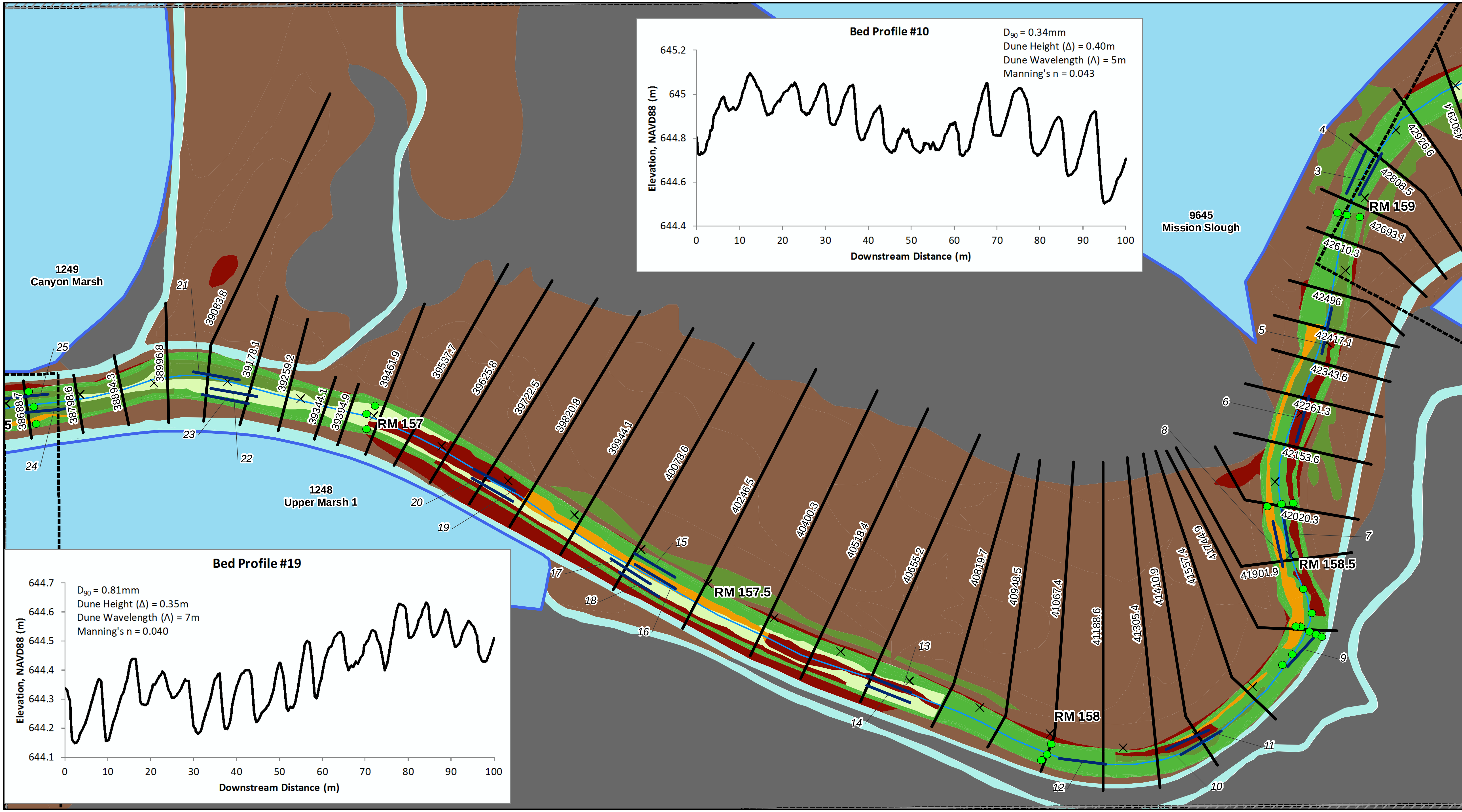
0.016 - 0.019	0.040 - 0.044
0.020 - 0.024	0.045 - 0.049
0.025 - 0.029	0.050 - 0.075
0.030 - 0.034	0.076 - 0.100
0.035 - 0.039	> 0.1

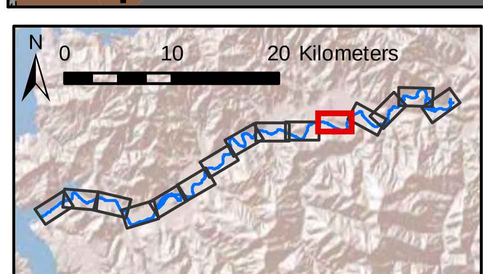
Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

N

0 100 200 Meters

Exhibit 8.j
Channel and Floodplain Roughness
RM 154.0 - RM 156.5
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)





Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

N

0 100 200 Meters

Exhibit 8.k
Channel and Floodplain Roughness
RM 156.5 - RM 159.2
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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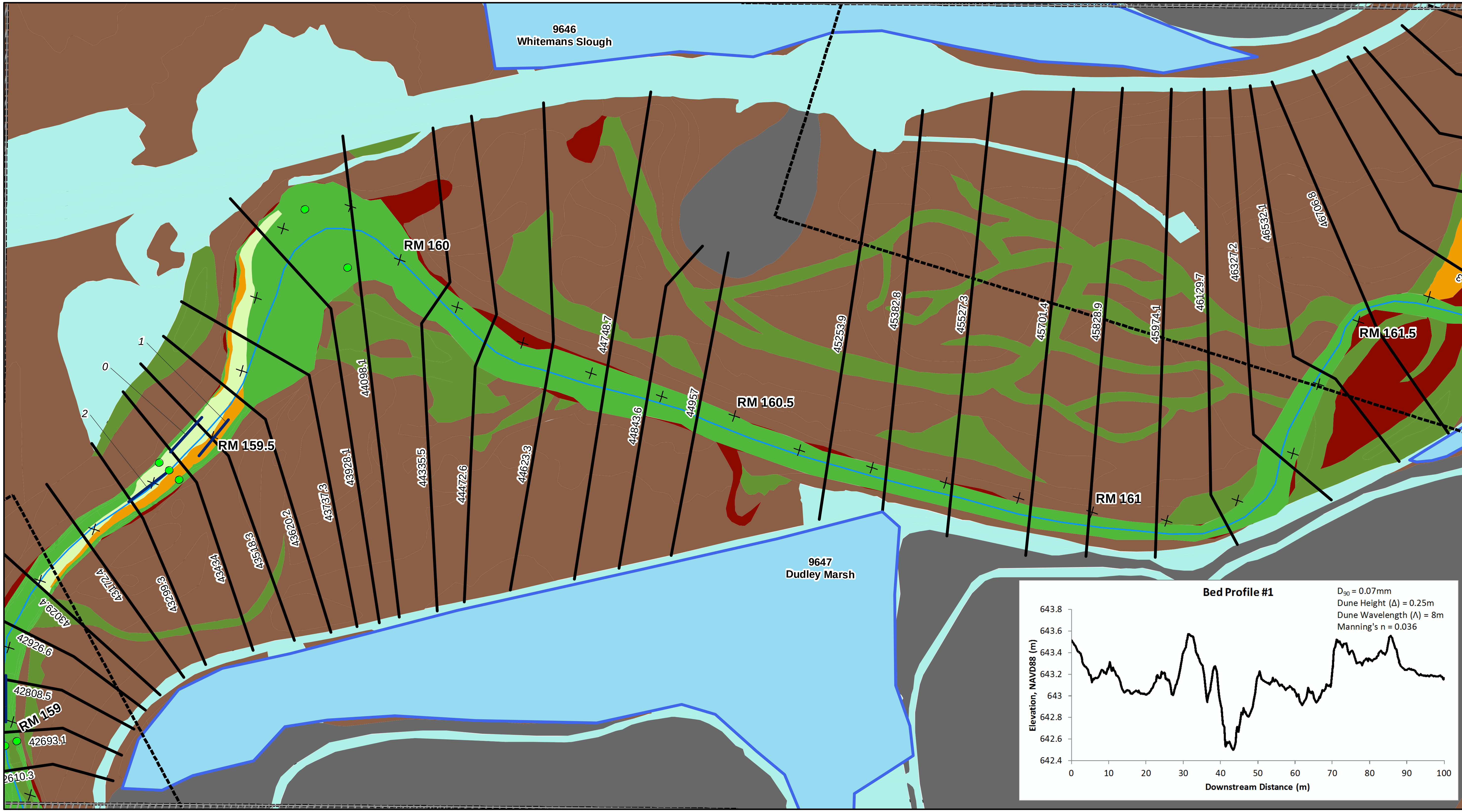

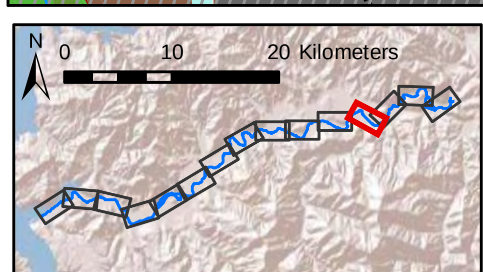

Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

0 100 200 Meters

Exhibit 8.l
Channel and Floodplain Roughness
RM 158.9 - RM 161.6
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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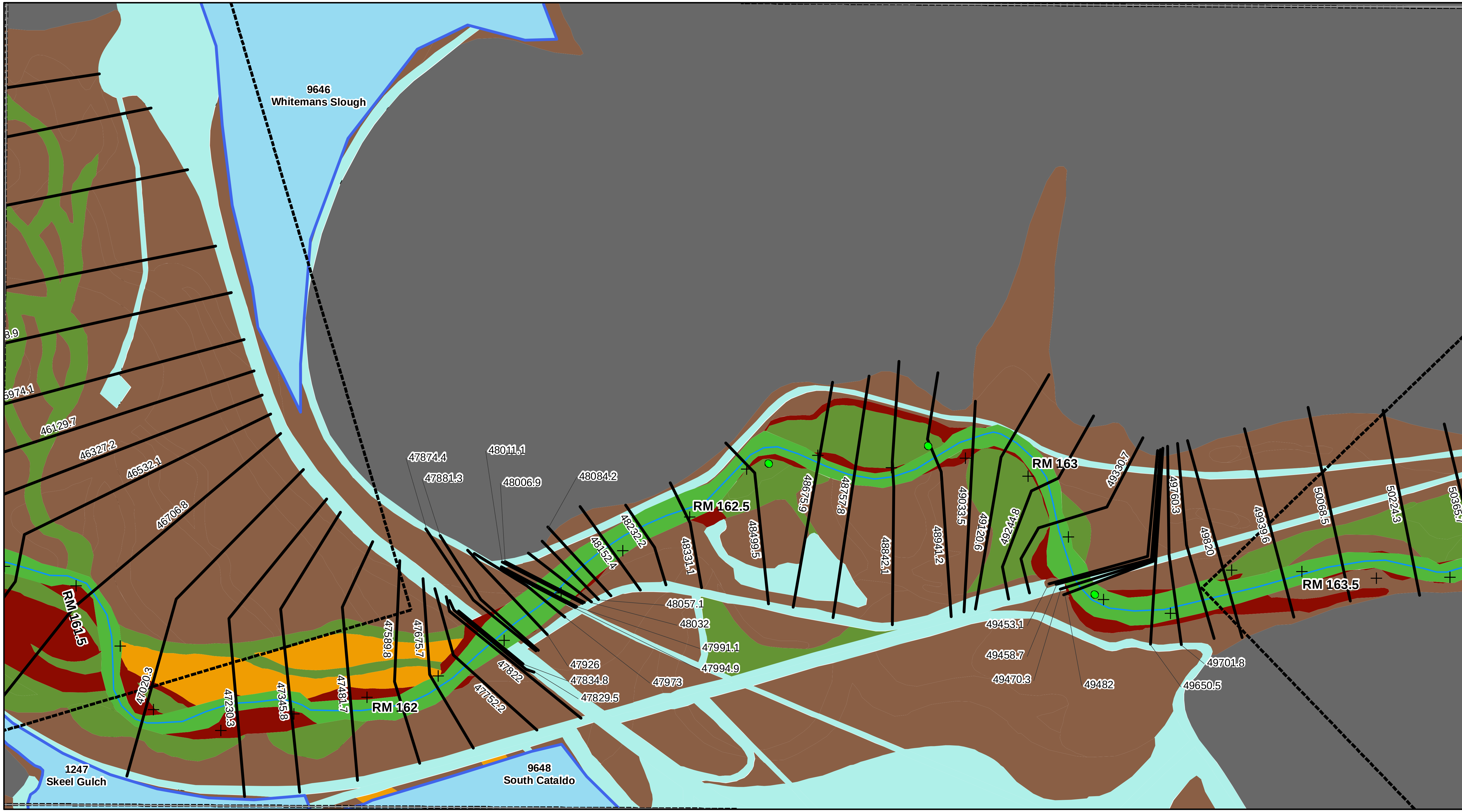
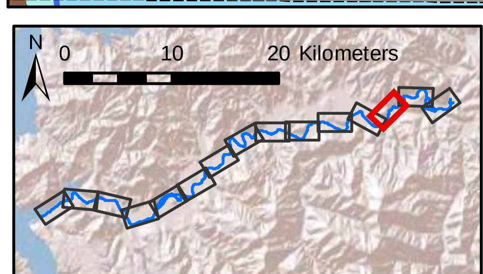




Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

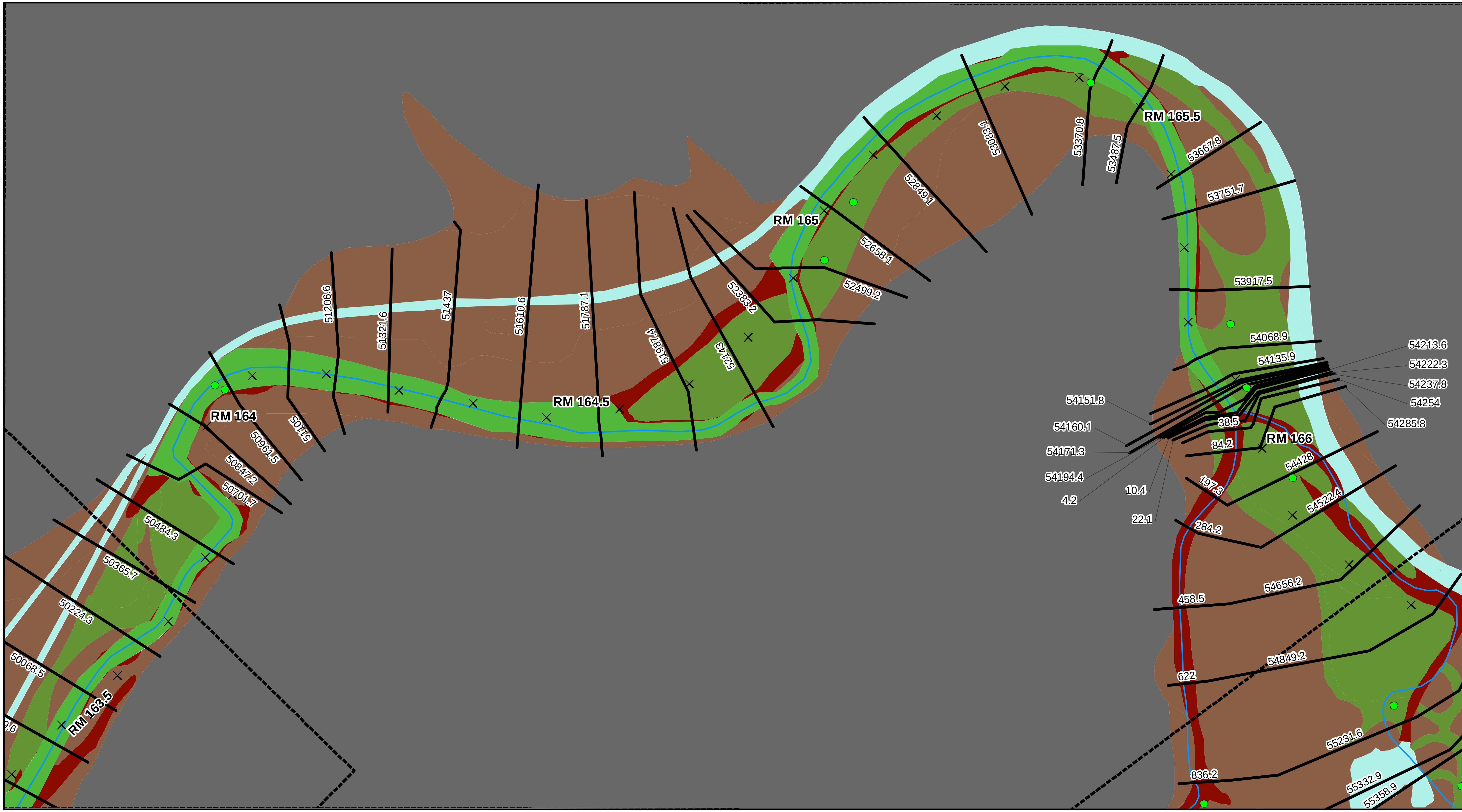
Manning's n Value	
0.016 - 0.019	0.040 - 0.044
0.020 - 0.024	0.045 - 0.049
0.025 - 0.029	0.050 - 0.075
0.030 - 0.034	0.076 - 0.100
0.035 - 0.039	> 0.1

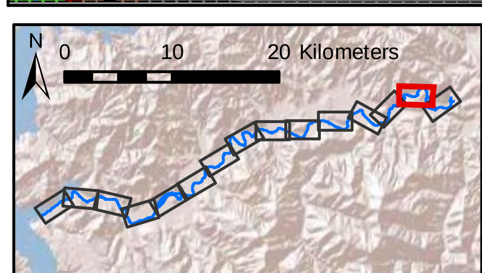
0 100 200 Meters

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

Exhibit 8.m
Channel and Floodplain Roughness
RM 161.4 - RM 163.7
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

\\OSPREY\GROUPS\WATER_RESOURCES\WREM\GARIGLIO\USEPA\CDA\BEDROUGHNESSMAPPING\GIS\MXD\BEDROUGHNESS_MAPBOOK.MXD FPG 12/05/2012 7:55 AM





Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

0.016 - 0.019	0.040 - 0.044
0.020 - 0.024	0.045 - 0.049
0.025 - 0.029	0.050 - 0.075
0.030 - 0.034	0.076 - 0.100
0.035 - 0.039	> 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

N

0 100 200 Meters

Exhibit 8.n
Channel and Floodplain Roughness
RM 163.4 - RM 166.3
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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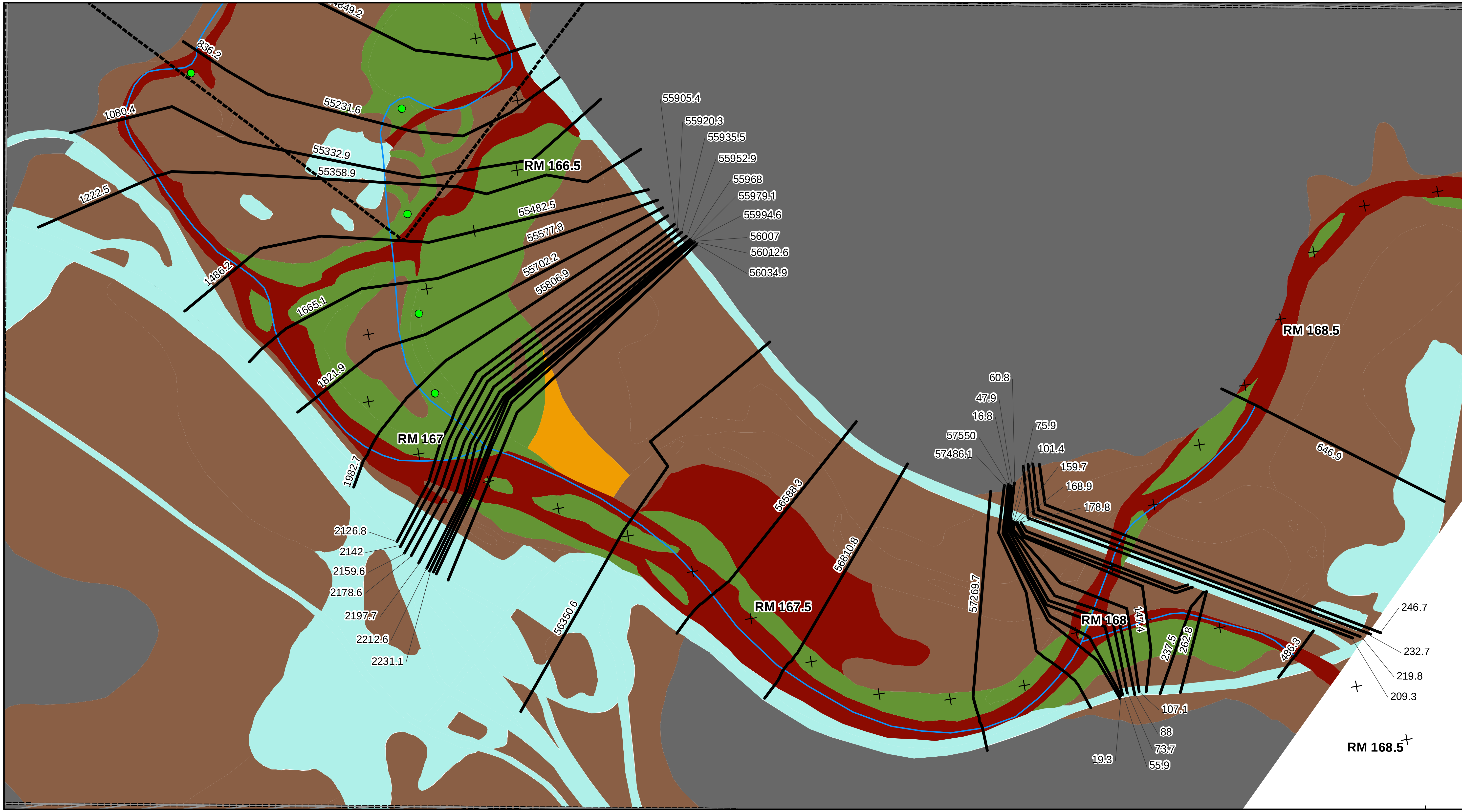

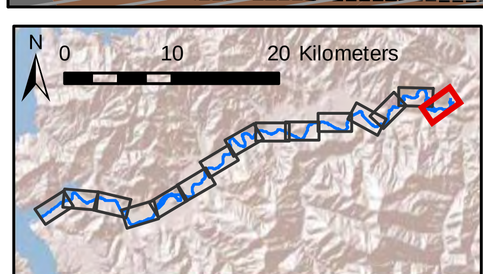

Legend

- Sediment Sample Locations
- Bedform Roughness Profiles
- River Mile
- Lakes, Marshes, Sloughs
- Model Cross Sections
- Model Centerline
- Map Tiles

Manning's n Value

- 0.016 - 0.019
- 0.020 - 0.024
- 0.025 - 0.029
- 0.030 - 0.034
- 0.035 - 0.039
- 0.040 - 0.044
- 0.045 - 0.049
- 0.050 - 0.075
- 0.076 - 0.100
- > 0.1

Notes:
1. Bedform profile stationing increases in the downstream direction.
2. Bathymetric survey data (CH2M HILL, 2012) and channel bed sediment samples (CH2M HILL, 2010-2011) were used to determine channel Manning's n roughness coefficients from RM 132.7 - RM 159.8.
3. Surficial geology, wetlands, and deepwater habitat map (USGS, 1999) was used to determine floodplain Manning's n roughness coefficients and channel Manning's n coefficients outside of RM 132.7 - RM 159.8.

0 100 200 Meters

Exhibit 8.o
Channel and Floodplain Roughness
RM 166.3 - RM 168.8 (NF) & RM 168.5 (SF)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

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Bookstrom Subclass Label	Bookstrom Subclass Description (from Cowardin, 1979)	Associated Hydraulic Roughness Category in HEC-RAS Reference Manual Table 3-1	Summer Roughness	Winter Roughness
	not classified	5.i.2. - asphalt, rough	0.016	0.016
al	algal	1.d. - clean, winding, some pools and shoals, some weeds and stones	0.040	0.040
f	forest, undivided (terrestrial)	3.c.2 - light brush and trees	0.06	0.05
fe	forest, predominantly evergreen	3.d.4. - heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.1	0.1
mpsf	moss (aquatic) with persistent, shrub, and/or forest cover	1.d. - clean, winding, some pools and shoals, some weeds and stones	0.040	0.040
np	non-persistent (emergent)	1.g - sluggish reaches, weedy, deep pools	0.07	0.03
npvr	non-persistent and vascular, rooted	1.g - sluggish reaches, weedy, deep pools	0.07	0.05
p	persistent (emergent)	1.g - sluggish reaches, weedy, deep pools	0.07	0.06
pnp	persistent and non-persistent (emergent)	1.g - sluggish reaches, weedy, deep pools	0.07	0.055
ps	persistent and scrub-shrub	3.c.5 - medium to dense brush, in summer	0.15	0.07
psf	persistent, scrub-shrub and/or forest	3.d.4. - heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.13	0.7
pvr	persistent and vascular, rooted	3.c.5 - medium to dense brush, in summer	0.08	0.06
sf	scrub-shrub and/or forest	3.d.4. - heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.13	0.7
usb	unknown submergent	2.a - bottom: gravels, cobbles, and a few boulders	0.04	0.04
vr	vascular, rooted (aquatic)	1.g - sluggish reaches, weedy, deep pools	0.07	0.055
vsa	vegetation sparse to absent	3.a.1 Pasture, no brush, short grass	0.03	0.03
vsad	vegetation sparse to absent or dead	2.a - bottom: gravels, cobbles, and a few boulders	0.04	0.04

EXHIBIT 10. STORAGE AREA SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Name	River Connection 1	Storage Area Connection 1	Storage Area Connection 2	Storage Area Connection 3	Other Connection
1238 Lane Marsh 2		1258 Lane Marsh 1 via 1284			
1239 Swan Lake 2	LS 10188.80	1240 Blue Lake via 1270	1265 Swan Lake 1 via 1274		
1240 Blue Lake	LS 8514	1239 Swan Lake 2 via 1270			
1241 Black Lake	LS 11307.36	1267 Lamb Peak 1 via 1272	1266 Black Lake 1 via 1273		
1242 Cave Lake	LS 15539.20	1266 Black Lake 1 via 1275	1264 Medicine 4 via 1276		
1243 Medicine Lake 2	LS 21342	1262 Medicine 3 via 1278	1263 Robinson Creek Marsh via 1279		
1244 Thompson Lake	LS 4077.921 & LS 2926.546	1246 Bare Marsh via 1269			
1245 Anderson Lake	LS 2940				
1246 Bare Marsh	LS 6483.716	1244 Thompson Lake via 1269			
1247 Skeel Gulch	LS 47394.16	9648 South Cataldo via 9649			
1248 Upper Marsh 1	LS 39929.08	1250 Upper Marsh 2 via 1287			
1249 Canyon Marsh	LS 38969.57				RS 38453.5 via Pump FOJC_PS
1250 Upper Marsh	LS 38257.96	1248 Upper Marsh 1 via 1287			
1251 Orling Slough	LS 36979.40				
1252 Bull Run Lake 1	LS 35576.07 & LS 33710.1	1254 Bull Run Lake 2 via 1286			
1253 Porter Slough	LS 34066.33				
1254 Bull Run Lake 2	LS 33421.98	1255 Black Rock Slough via 1285	1252 Bull Run Lake 1 via 1286		
1255 Black Rock Slough	LS 32950.61 & LS 30864	1254 Bull Run Lake 2 via 1285			

EXHIBIT 10. STORAGE AREA SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Name	River Connection 1	Storage Area Connection 1	Storage Area Connection 2	Storage Area Connection 3	Other Connection
1256 Strobl Field	LS 28425 & LS 29858.62				
1257 Strobl Marsh	LS 26890.91	1261 Killarney Lake via 1283			
1258 Lane Marsh 1	LS 28397.05	1238 Lane Marsh 2 via 1284			
1259 Moffit Slough	LS 20090	1260 Campbell Marsh via 1280	1261 Killarney Lake via 1281		RS 3233.648
1260 Campbell Marsh	LS 22572.89	1259 Moffit Slough via 1280	1261 Killarney Lake via 1282	1261 Killarney Lake via 9565	
1261 Killarney Lake	LS 23463	1259 Moffit Slough via 1281	1260 Campbell Marsh via 1282	1257 Strobl Marsh via 1283	1260 Campbell Marsh via 9565
1262 Medicine Lake 3	LS 19241	1264 Medicine Lake 4 via 1277	1243 Medicine Lake 2 via 1278		
1263 Robinson Creek Marsh	LS 23762.52	1243 Medicine Lake 2 via 1279			
1264 Medicine Lake 4		1242 Cave Lake via 1276	1262 Medicine Lake 3 via 1277		
1265 Swan Lake 1	LS 14677, LS 12038 & LS11987.66	1239 Swan Lake 2 via 1274			RS 22.55938
1266 Black Lake 1	LS 13318.45	1241 Black Lake 2 via 1273	1242 Cave Lake via 1275		
1267 Lamb Peak 1	LS 10896.41	1268 Lamb Peak 2 via 1271	1241 Black Lake 2 via 1241		
1268 Lamb Peak 2	LS 8784.441	1267 Lamb Peak 1 via 1271			
9645 Mission Slough	LS 43171				
9646 Whitemans Slough	LS 46550 & 47980				
9647 Dudley Marsh	LS 45436.79				
9648 South Cataldo		1247 Skeel Gulch via 9649			
9651 Rose Lake	LS 33856.13 & 33710				

EXHIBIT 11. STORAGE AREA CONNECTION SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Name	From	To	Culvert (Length [m], Invert Elevation [m, NAVD 88]	Lowest Elevation (m, NAVD 88)
1269	1246 Bare Marsh	1244 Thompson Lake	1m; IE 6400	650.89
1270	1239 Swan Lake 2	1240 Blue Lake		649.871
1271	1267 Lamb Peak 1	1268 Lamb Peak 2		646.772
1272	1241 Black Lake 2	1267 Lamb Peak 1		651.489
1273	1266 Black Lake 1	1241 Black Lake 2		651.292
1274	1265 Swan Lake 1	1239 Swan Lake 2		648.461
1275	1242 Cave Lake	1266 Black Lake 1		651.409
1276	1264 Medicine Lake 4	1242 Cave Lake		647.22
1277	1262 Medicine Lake 3	1264 Medicine Lake 4	3.06m x 3.06m box culvert, IE 647.21	650.899
1278	1243 Medicine Lake 2	1262 Medicine Lake 3	1.6m; IE 647.56	651.3
1279	1263 Robinson Creek Marsh	1243 Medicine Lake 2	1.83m; IE 647.94 0.61m; IE 648.16	651.356
1280	1260 Campbell Marsh	1259 Moffit Slough		646.927
1281	1261 Killarney Lake	1259 Moffit Slough		648.04
1282	1261 Killarney Lake	1260 Campbell Marsh		647.699
1283	1257 Strobl Marsh	1262 Killarney Lake		648.93
1284	1258 Lane Marsh 1	1238 Lane Marsh 2		647.491
1285	1254 Bull Run Lake 2	1255 Black Rock Slough	0.65m; IE 649.48 0.6m; IE 649.53	650.054
1286	1252 Bull Run Lake 1	1254 Bull Run Lake 2	0.9m; IE 651.03	651.902
1287	1248 Upper Marsh 1	1250 Upper Marsh 2	1.6m; IE 650.08	651.151
9565	1261 Killarney Lake	1260 Campbell Marsh		649.289
9649	1247 Skeel Gulch	9648 South Catald		652.71

EXHIBIT 12. LATERAL STRUCTURE SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Name	Tailwater Connection (Storage Area, unless otherwise noted as River Station [RS])	Headwater Overbank Position	Culvert (Diameter [m], Invert Elevation [m, NAVD 88]	Lowest Elevation (m, NAVD 88)
55978	Braided South RS: 2212.580	Left		656.084
55904	Braided South RS: 2126.787	Left		655.488
47980	9646 Whitemans Slough	Right		653.763
47394.16	1247 Skeel Gulch	Left		650.93
46550	9646 Whitemans Slough	Right	0.76m, IE 651.23 0.76m, IE 650.46 1.52m, IE 648.19 0.61m, IE 649.66	655.164
45436.79	9647 Dudley Marsh	Left		649.019
43171	9645 Mission Slough	Right		647.354
39929.08	1248 Upper Marsh 1	Left		652.481
38969.57	1249 Canyon Marsh	Right	Pump Station from Fourth of July Creek	652.656
38257.96	1250 Upper Marsh 2	Left	0.61m, IE 651.39	649.829
36979.4	1251 Orling Slough	Right		649.93
35576.07	1252 Bull Run Lake 1	Left		652.102
34066.33	1253 Porter Slough	Right		652.385
33856.13	9651 Rose Lake	Right		653.7
33710.1	1252 Bull Run Lake 1	Left		652.163
33710	9651 Rose Lake	Right	1.86m; IE 645.76	652.724
33421.98	1254 Bull Run Lake 2	Left		651.614
32950.61	1255 Black Rock Slough	Left		651.218
30864	1255 Black Rock Slough	Left		648.435
29858.62	1256 Strobl Field	Right		653.068
28425	1256 Strobl Field	Right		648.375
28397.05	1258 Lane Marsh 1	Left		649.751

EXHIBIT 12. LATERAL STRUCTURE SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Name	Tailwater Connection (Storage Area, unless otherwise noted as River Station [RS])	Headwater Overbank Position	Culvert (Diameter [m], Invert Elevation [m, NAVD 88]	Lowest Elevation (m, NAVD 88)
26890.91	1257 Strobl Marsh	Right		649.835
23762.52	1263 Robinson Creek Marsh	Left	0.61m; IE 647.85	651.204
23463	1261 Killarney Lake	Right		645.49
22572.89	1260 Campbell Marsh	Right		647.067
21342	1243 Medicine Lake 2	Left		651.316
20090	1259 Moffit Slough	Right		649.49
19241	1262 Medicine Lake 3	Left		646.432
18251	Blessing Slough RS 3233.648	Right		649.555
17115.53	Blessing Slough RS 2665	Right		649.27
16168.2	Blessing Slough RS 1763.489	Right		649.642
15539.2	1242 Cave Lake	Left		649.5
14677	1265 Swan Lake 1	Right		649.649
13318.45	1266 Black Lake 1	Left		651.213
12038	1265 Swan Lake 1	Right		647.48
11987.66	1265 Swan Lake 1	Right		648.32
11307.36	1241 Black Lake 2	Left		647.584
10896.41	1267 Lamb Peak 1	Left		650.868
10188.8	1239 Swan Lake 2	Right		649.004
8784.441	1268 Lamb Peak 2	Left	1.00m; IE 650.00	651.179
8514	1240 Blue Lake	Right		647.26
6483.716	1246 Bare Marsh	Right		649.52
4077.921	1244 Thompson Lake	Right		647.21
2940	1245 Anderson Lake	Left		647.2
2926.546	1244 Thompson Lake	Right		650.592

Structure Containing Culvert	Diameter (m), Length (m), Upstream Invert Elevation (m, NAVD 88), Downstream Invert Elevation (NAVD 88)	Upstream Connected Feature	Downstream Connected Feature	Notes
Blessing Slough Bridge RS=1690	0.50, 6, 649.03, 646.52	XS 1694	XS 1674	Presence assumed from aerial image. May in fact represent groundwater flow through berm visible in aerial image.
Meander LS 46550 # 1	0.76, 51, 651.53, 651.23	XS 46706.79	SA 9646 Whitemans Slough	From 2005 TerraGraphics survey, provided by Paul Hansen at USACE
Meander LS 46550 # 2	0.76, 55, 650.47, 650.68	XS 46706.79	SA 9646 Whitemans Slough	From 2005 TerraGraphics survey, provided by Paul Hansen at USACE
Meander LS 46550 # 3	1.52, 270, 648.19, 650.37	XS 46706.79	SA 9646 Whitemans Slough	From 2005 TerraGraphics survey, provided by Paul Hansen at USACE
Meander LS 46550 # 4	0.61, 80, 649.66, 650.62	XS 46706.79	SA 9646 Whitemans Slough	From 2005 TerraGraphics survey, provided by Paul Hansen at USACE
Meander LS 38257.961	0.61, 17.7, 651.39, 651.39			
Meander LS 33710	1.86, 10, 645.76, 645.76	XS 32846.24, Right Overbank	SA 9651 Rose Lake	Geometry measured in field. Flaps prevent positive flow. Gate controlled by F&G.
Meander LS 23762.52	0.61, 38, 647.85, 647.85	XS 21383.64, Left Overbank	SA 1263 Robinson Creek Marsh	Geometry from Schlepp Field plans. Flap gate prevents positive flow. Gate allows culvert to be closed; assumed always open.
Meander LS 8784.441	1.00, 10, 650.00, 650.00	XS 7348.942, Left Overbank	SA 1268 Lamb Peak 2	Presence and geometry of culvert assumed.
SA Conn 1269	1.00, 18, 649.00, 649.00	SA 1246 Bare Marsh	SA 1244 Thompson Lake	Location and presence of culvert assumed.
SA Conn 1277	3.06m x 3.06m box, 15, 647.21, 647.21	SA 1262 Medicine Lake 3	SA 1264 Medicine Lake 4	Added in lieu of tie channel opening through storage area connection. Geometry based on survey.
SA Conn 1278	1.60, 12, 647.56,	SA 1243	SA 1262	Allows Robinson Creek to pass.

EXHIBIT 13. CULVERT SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Structure Containing Culvert	Diameter (m), Length (m), Upstream Invert Elevation (m, NAVD 88), Downstream Invert Elevation (NAVD 88)	Upstream Connected Feature	Downstream Connected Feature	Notes
	647.56	Medicine Lake 2	Medicine Lake 3	Geometry measured in field.
SA Conn 1279 #1	0.61, 18, 648.16, 648.16	SA 1263 Robinson Creek Marsh	SA 1243 Medicine Lake 2	Connects East Schlepp Field with West Schlepp Field. Assume gate is always open.
SA Conn 1279 #2	1.83, 14, 647.94, 647.94	SA 1263 Robinson Creek Marsh	SA 1243 Medicine Lake 2	Allows Robinson Creek to pass. Size and geometry from Schlepp Field plans. Assume always open.
SA Conn 1285 #1	0.60, 4, 649.53, 649.53	SA 1254 Bull Run Lake 2	SA 1255 Black Rock Slough	Observed and measured in field.
SA Conn 1285 #2	0.65, 4, 649.48, 649.48	SA 1254 Bull Run Lake 2	SA 1255 Black Rock Slough	Observed and measured in field.
SA Conn 1286	0.90, 651.03, 651.03	SA 1252 Bull Run Lake 1	SA 1254 Bull Run Lake 2	Observed and measured in field.
SA Conn 1287	1.60, 650.08, 650.08	SA 1248 Upper Marsh 1	SA 1250 Upper Marsh 2	Observed and measured in field.

EXHIBIT 14. BRIDGE SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Bridge Cross Section ID	Description	Geometry Notes
Blessing Slough 1690	Berm/road observed in aerial imagery. Not accessible in field.	Geometry from LiDAR. Presence of culvert assumed.
Meander 49463.66	Trail of the Coeur d'Alenes, near Cataldo.	See photos from 10/2009 float trip #911 & #914. No piers.
Meander 47988.06	E. Canyon Road	See photos from 10/2009 float trip #954-958. Two piers; dimensions estimated from photos.
Meander 47857.58	Interstate 90	See photos from 10/2009 float trip #959-967. Six piers; dimensions estimated from photos.
Meander 33730.61	Rose Lake Bridge	See photos from 10/2009 float trip #984, 987. Three piers; dimensions estimated from photos.
Meander 28468.71	Highway 3, near Black Rock Slough	See photos from 10/2009 float trip #1013, #1017, #1022. Two piers; dimensions estimated from photos.
Meander 2966.279	Springston Bridge (Anderson	See photos from 10/2009 float trip #655-657. Eight

Bridge Cross Section ID	Description	Geometry Notes
	Lake Road)	piers; dimensions estimated from photos.
Meander 59.82124	Highway 97, near Harrison	See photos from 10/2009 float trip #665-668. Two piers; dimensions estimated from photos.
North Fork 194.4282	Trail of the Coeur d'Alenes, near Enaville	See photos from 10/2009 float trip #691, #694. One pier; dimensions estimated from photos.

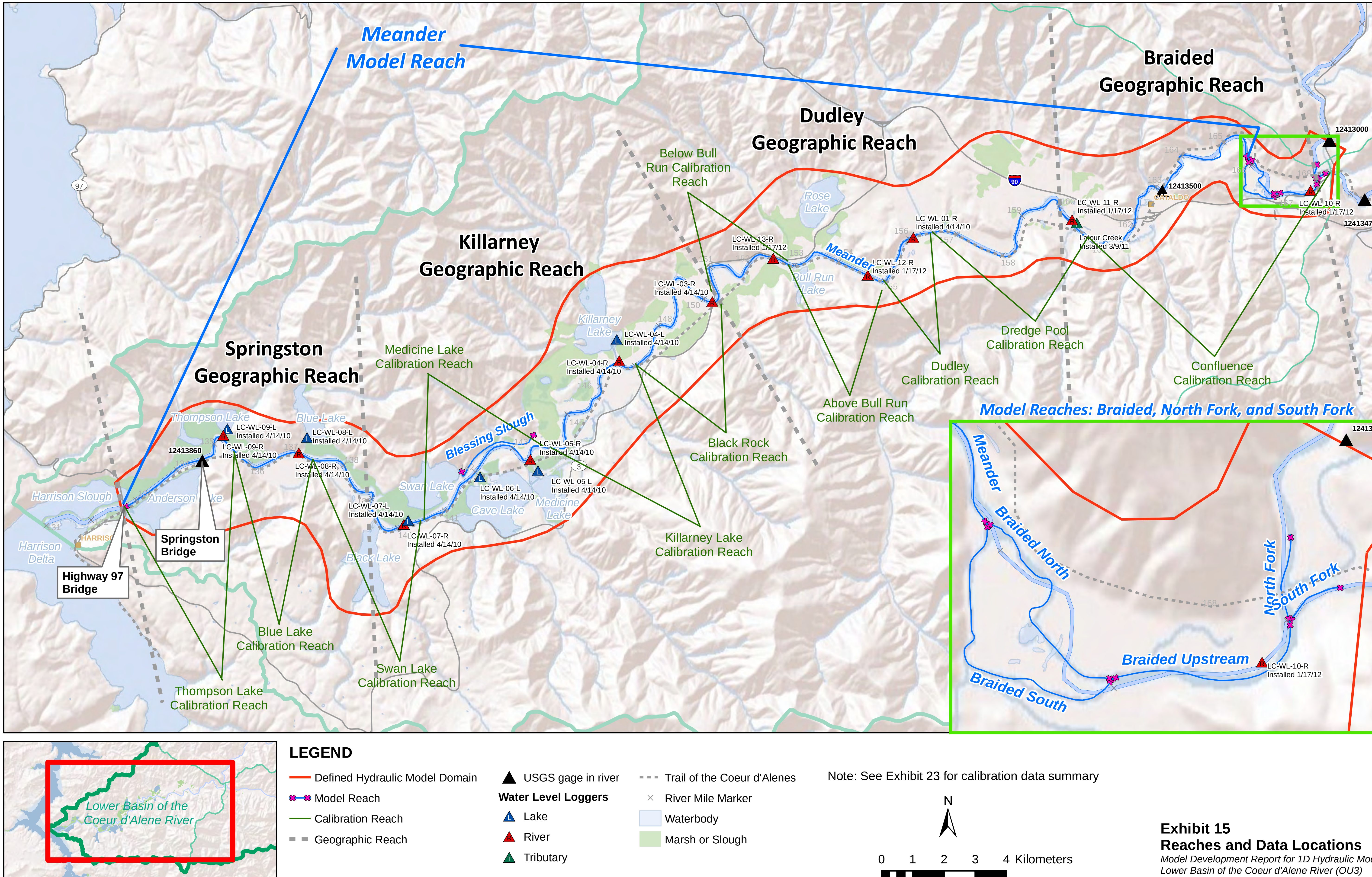


Exhibit 15
Reaches and Data Locations
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

\\ROSA\PROJ\USEPA\382081BUNKERHILL\LOWERBASIN\GIS\MAPFILES\2013\MODEL REPORT\BOUNDARYCONDITION_CALIBRATIONDATALOCATIONS.MXD GGEE 3/19/2013 10:58:46 AM

CH2MHILL

Level Logger		2011 River Logger Adjustment (cm)	2012 River Logger Adjustment (cm)	2011 Lake Logger Adjustment (cm)
Thompson	LL-09	0.0	1.1	-1.1
Blue	LL-08	0.3	2.0	-0.8
Swan	LL-07	3.6	3.6	2.0
Cave (leveled to LL-05R)	LL-06	-	-	-3.4
Medicine	LL-05	5.0	4.5	0.3
Killarney	LL-04	-3.5	-3.3	-3.8
Black Rock	LL-03	-2.1	-2.3	-
Below Bull Run-R	LL-13	-	-2.2	-
Above Bull Run-R	LL-12	-	2.7	-
Dudley	LL-01	0.2	-0.7	-
Adjustment value used				

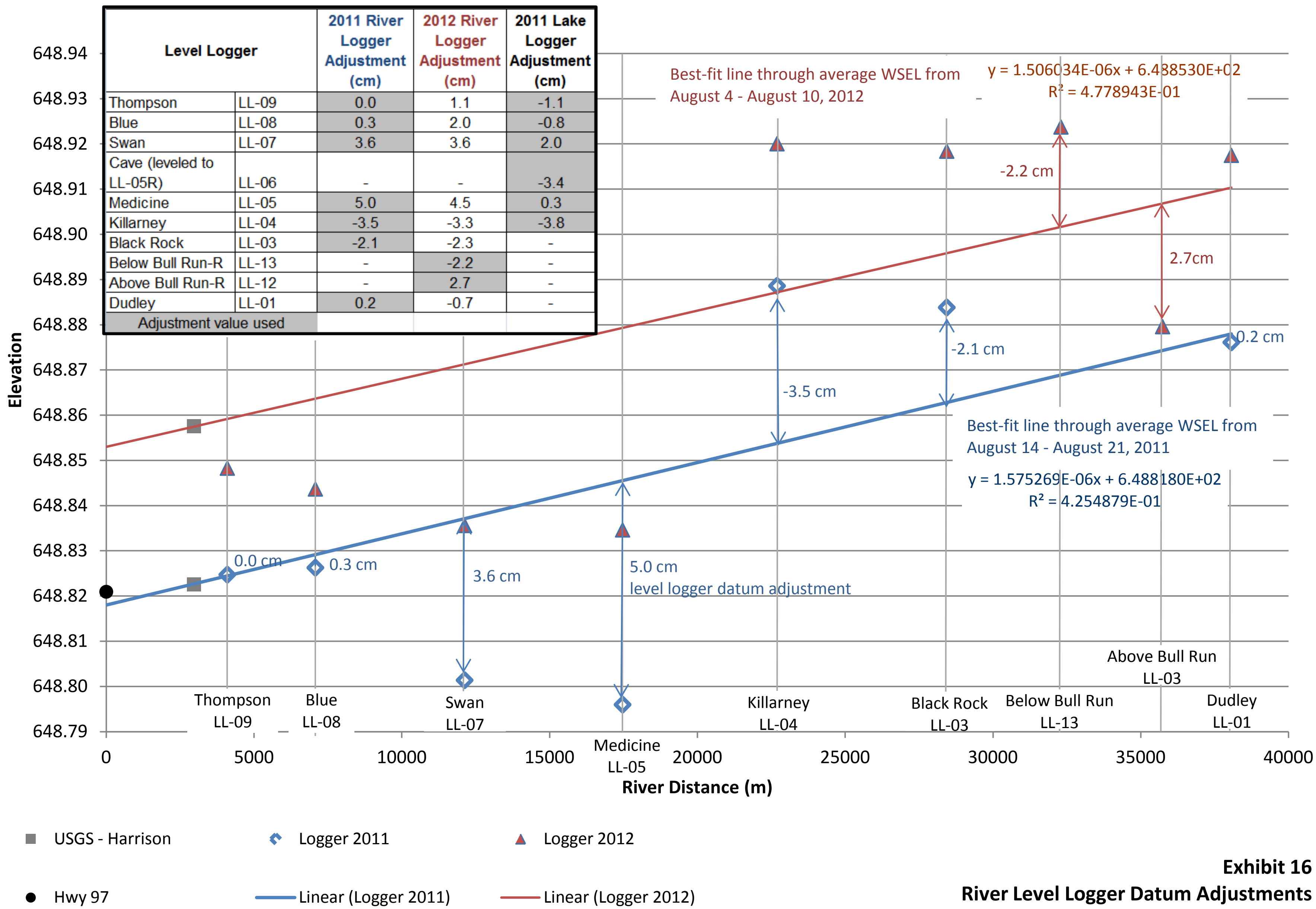


Exhibit 16

River Level Logger Datum Adjustments

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

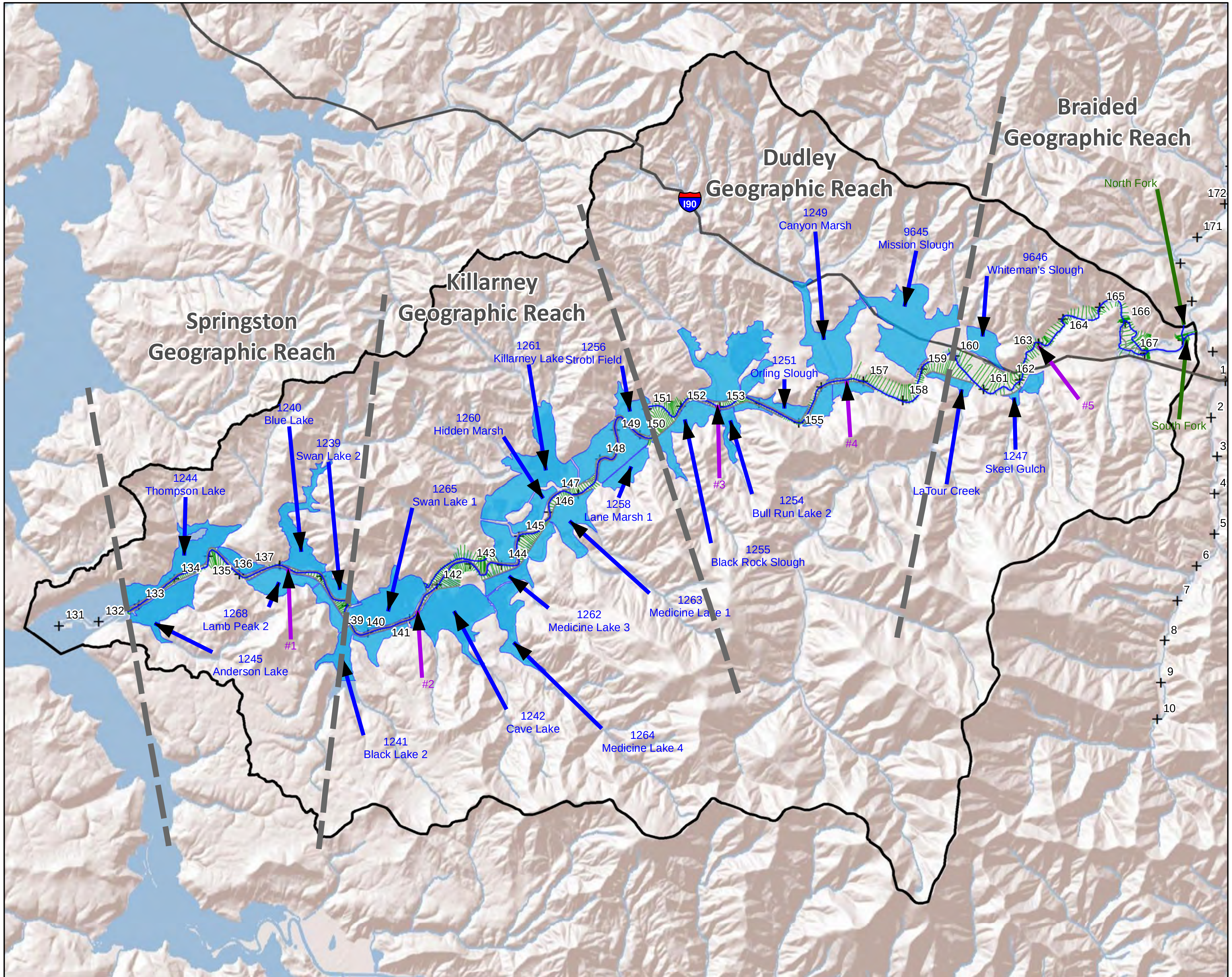
EXHIBIT 17. BOUNDARY CONDITION SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Description	Model Location	Source	Date Range	Notes
FH	Blessing Slough 3233.648	Q = 1 cms	All	Set for model stability
LI	Blessing Slough 1978.802	Min Q = 2 cms	All	Set for model stability
ND	Blessing Slough 22.55938	Friction Slope = 0.0001		
SD	Meander 0	USGS 12413860	3/1/04 to 12/30/11	Modified using modeled losses; see description in text
FH	North Fork 646.9193	USGS 12413000 – Enaville	10/1/86 to 2/14/12	
FH	South Fork 486.3487	USGS 12413470 - Pinehurst	9/12/87 to 2/14/12	
LI	Meander 7251.711	HEC-HMS output	3/15/04 to 12/30/11	Modified as described in Section 5.0, Calibration and Validation
LI	Meander 13823.04			
LI	Meander 32846.24			
LI	Meander 38798.62			
LI	Meander 49120.59			
LI	Meander 44957.04			
LI	SA 1239-SwanLake2			
LI	SA 1240-BlueLake			
LI	SA 1244-ThompsonLak			
LI	SA 1245-AndersonLak			
LI	SA 1268-LambPeak2			
LI	SA 1241-BlackLake2			
LI	SA 1242-CaveLake			
LI	SA 1247-SkeelGulch			
LI	SA 1249-CanyonMarsh			
LI	SA 1254-BullRunLa2			
LI	SA 1255-BlackRockSl			
LI	SA 1256-StroblField			
LI	SA 1258-Lane			
LI	SA 1260-CampbellMar			

EXHIBIT 17. BOUNDARY CONDITION SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Description	Model Location	Source	Date Range	Notes
LI	SA 1261-KillarneyLa	HEC-HMS output	3/15/04 to 12/30/11	Modified as described in Section 5.0, Calibration and Validation
LI	SA 1262-Medicine3			
LI	SA 1263-RobinsonCkM			
LI	SA 1264-Medicine4			
LI	SA 1265-SwanLake1			
LI	SA 1251-OrlingSloug			
LI	SA 9645-MissionSl			
LI	SA 9646-WhitemansSl			

FH = Flow Hydrograph; SH = Stage Hydrograph; LI = Lateral Inflow; NM = Normal Depth; SA = Storage Area



VICINITY MAP

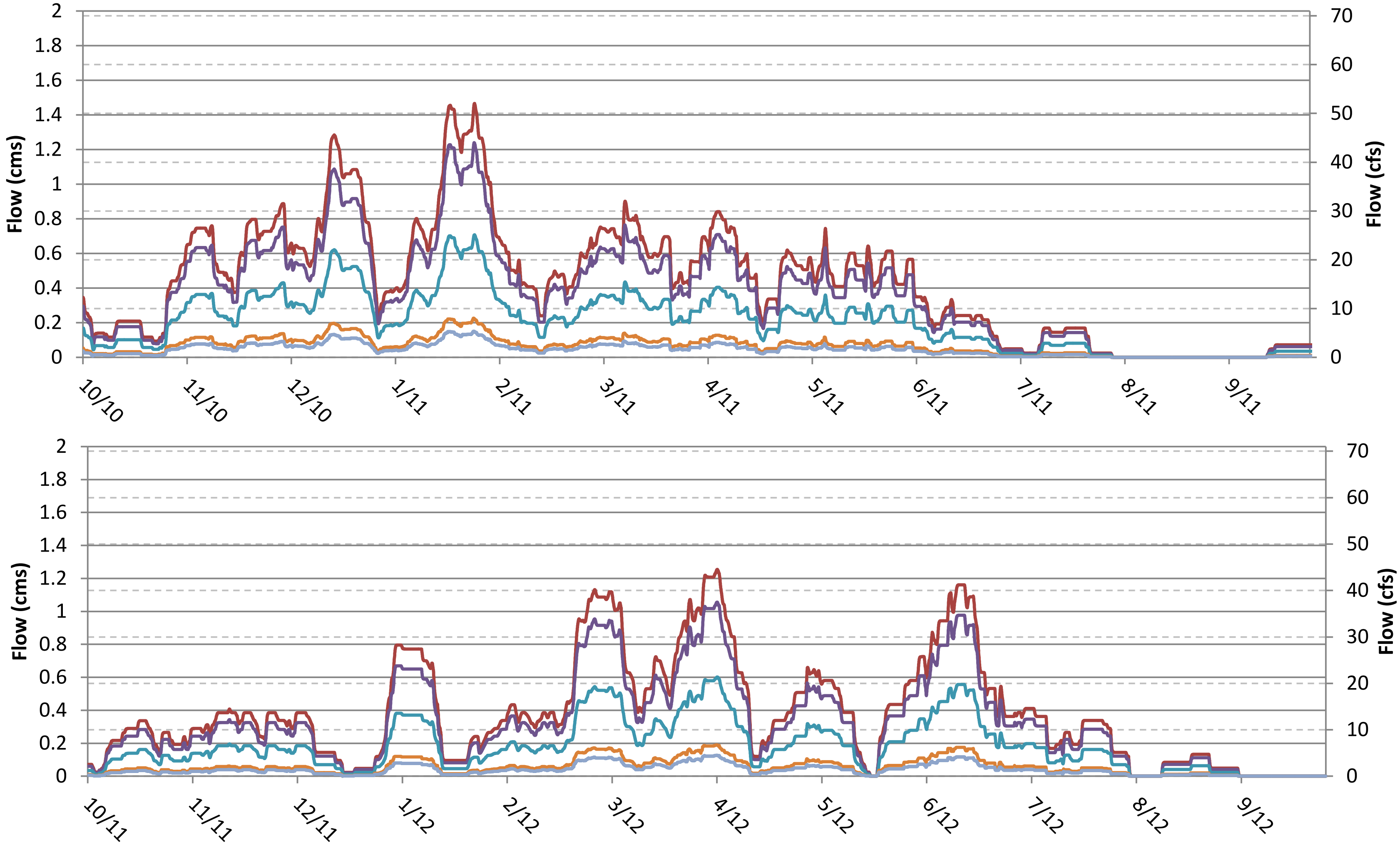
LEGEND

- Model Cross Sections
- Model Storage Areas
- Lower Basin Boundary
- HMS Tributary Inflow
- HMS Small Unnamed Catchments and Direct Rainfall
- USGS Gage Inflow

N

0 2 4 6
Kilometers

Exhibit 18
Flow Input Locations
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Note: Hydrographs shown in this figure are scaled HEC-HMS Hydrologic Model results. See Sections 4.5 and 5.3.

1239_SWANLAKE2
1240_BLUELAKE
1244_THOMPSONLAKE
1245_ANDERSONLAKE
1268_LAMBPEAK2
Small Unnamed Catchments and Direct Rainfall #1

Exhibit 19.a
Boundary Condition Inflows
Springston Geographic Reach Tributaries
(RM 132 to RM 138.9)

Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

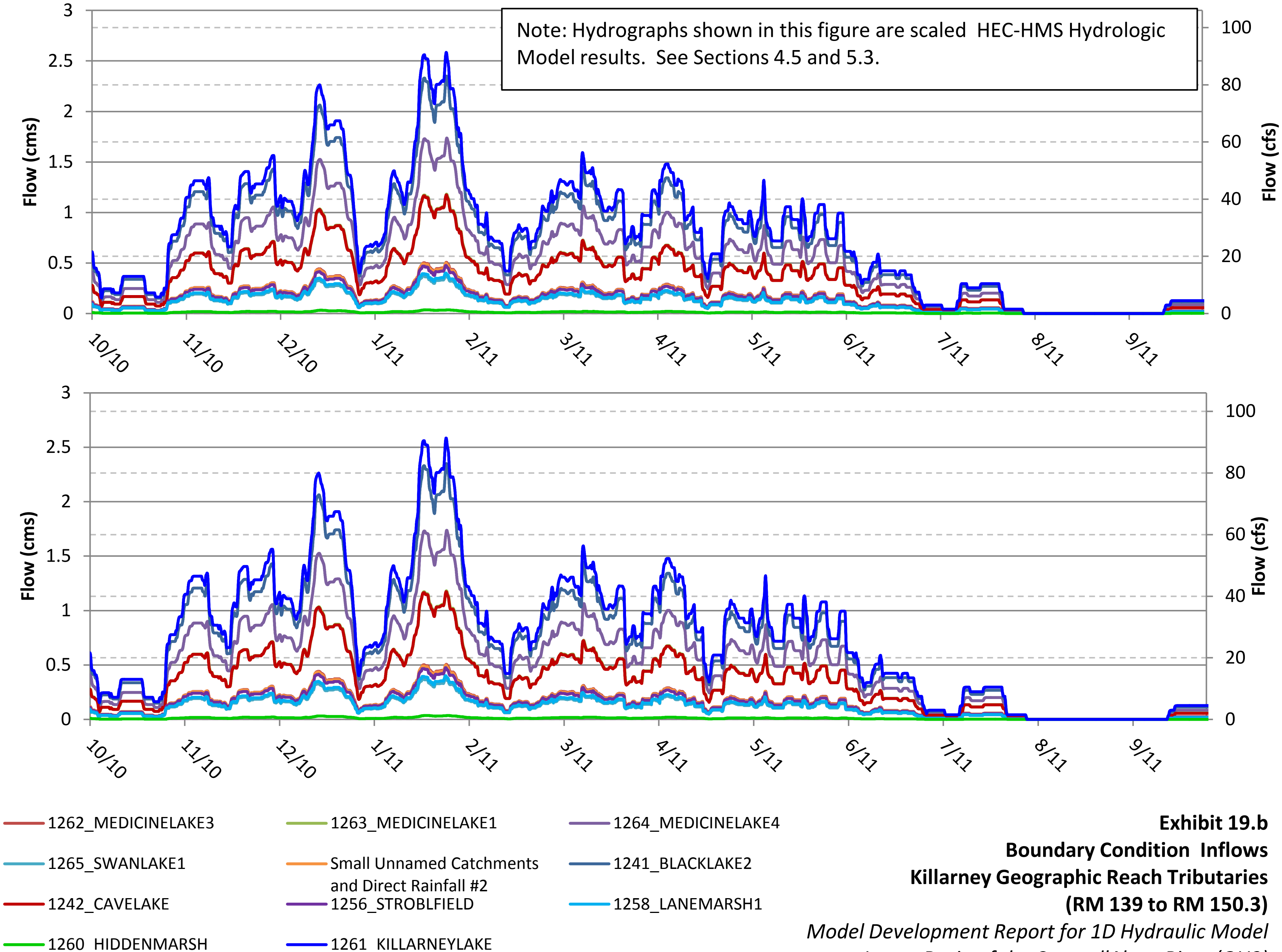


Exhibit 19.b
Boundary Condition Inflows
Killarney Geographic Reach Tributaries
(RM 139 to RM 150.3)

Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

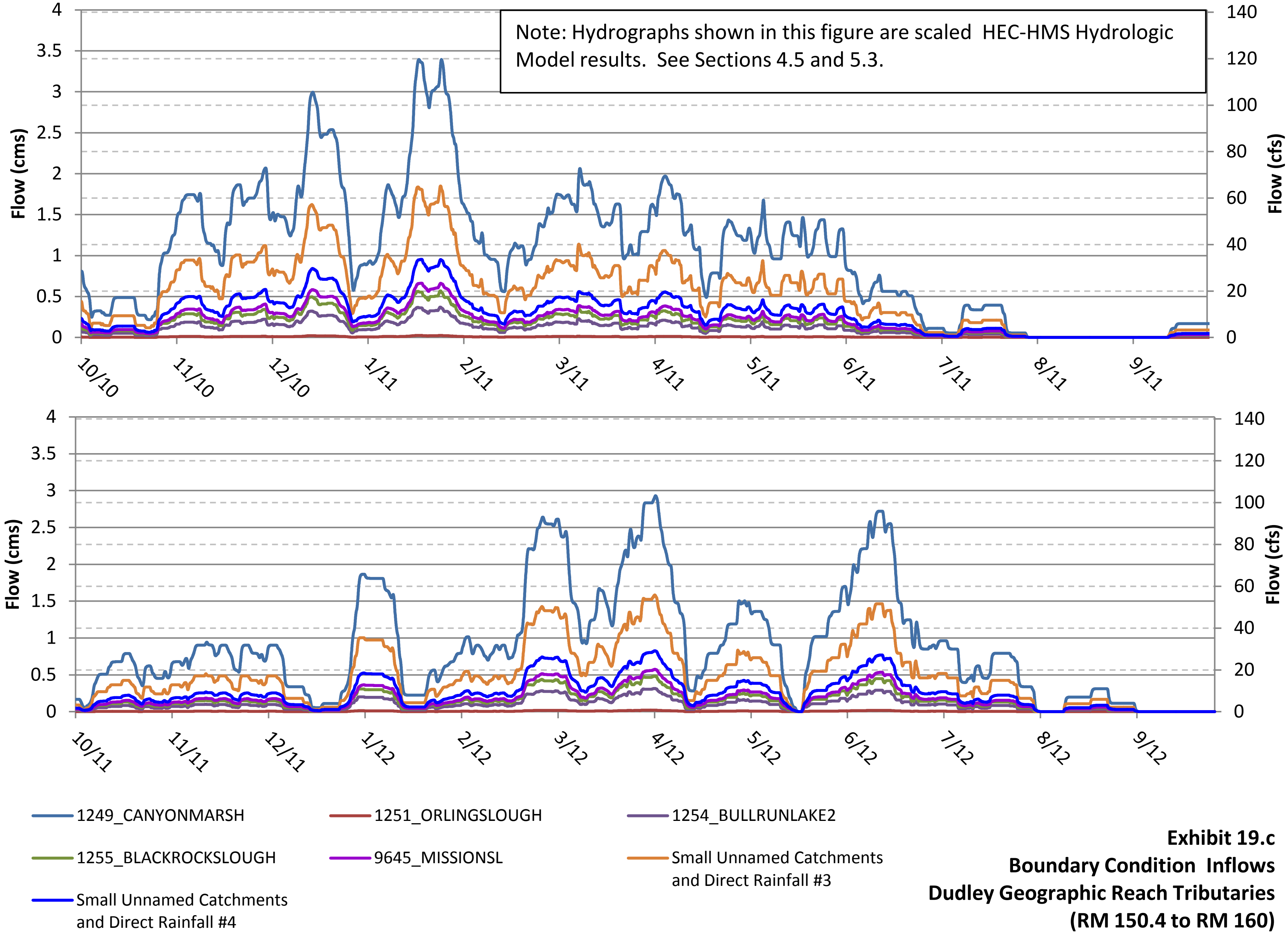
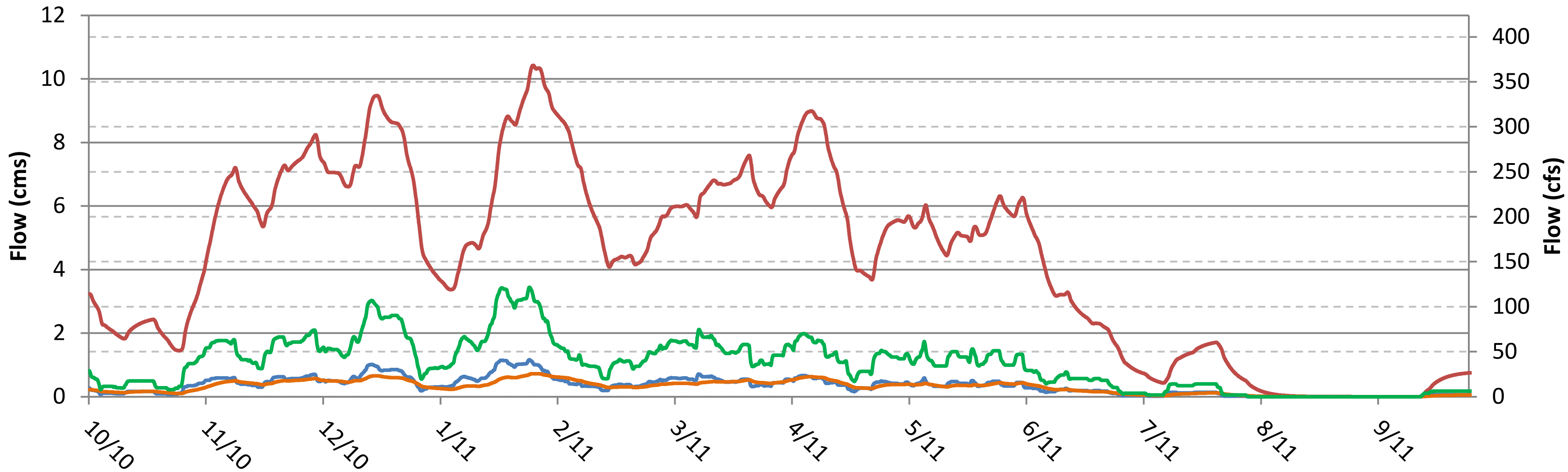
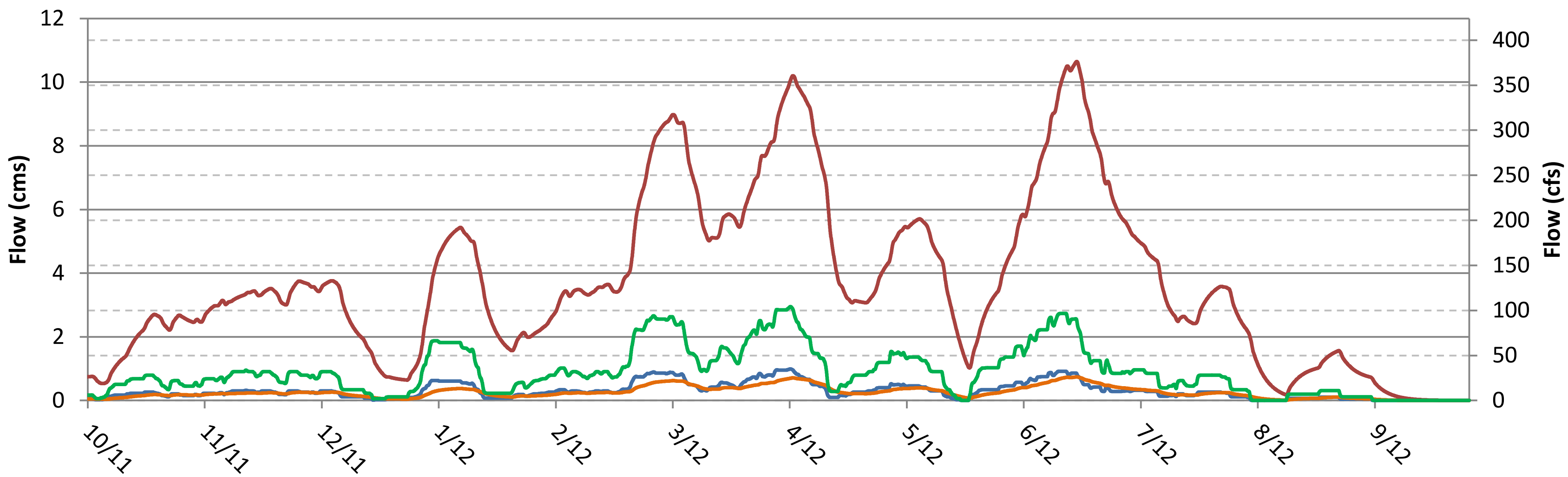


Exhibit 19.c
Boundary Condition Inflows
Dudley Geographic Reach Tributaries
(RM 150.4 to RM 160)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)





Note: Hydrographs shown in this figure are scaled HEC-HMS Hydrologic Model results. See Sections 4.5 and 5.3.

1247_SKEELGULCH

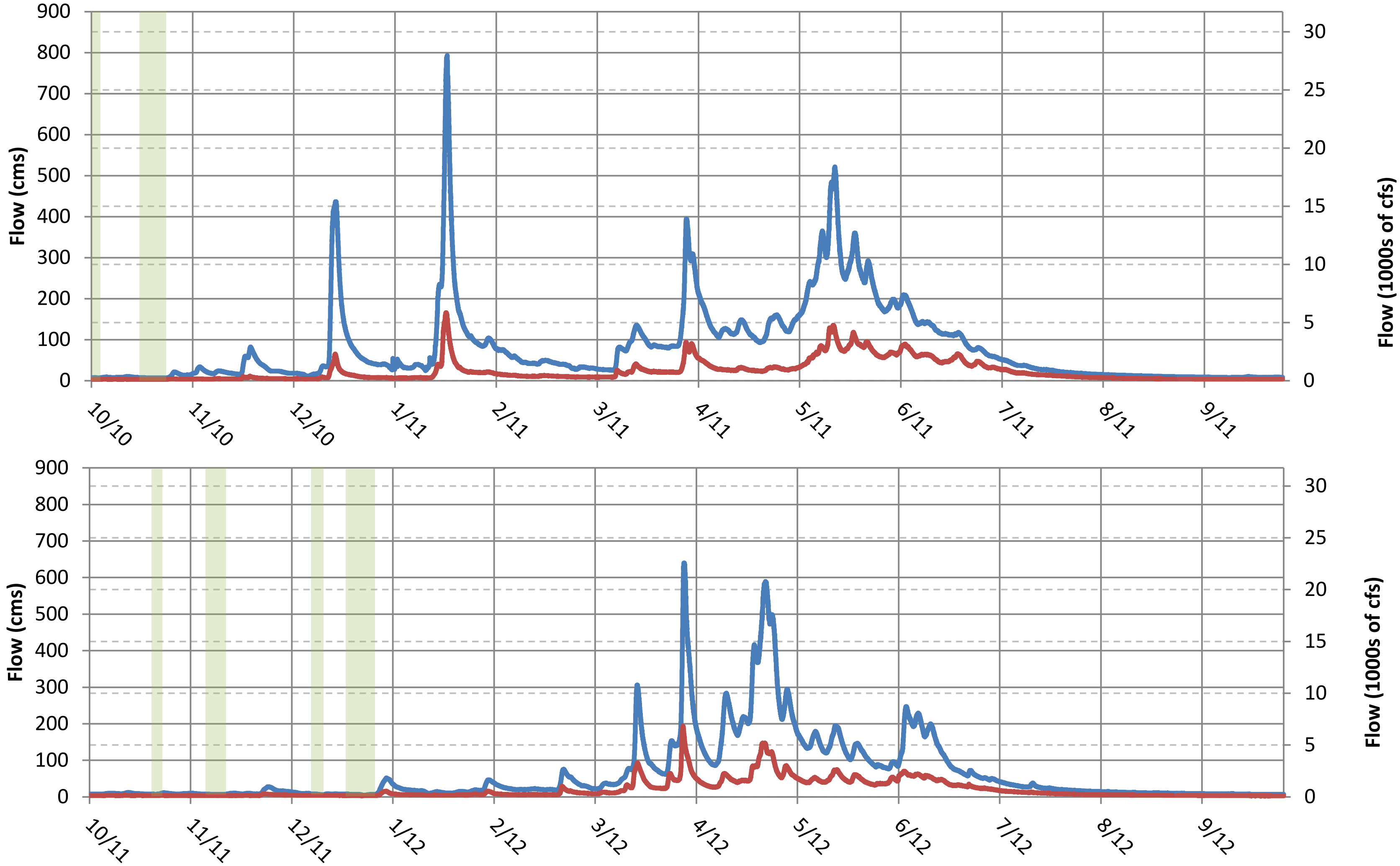
44957.05_LATOUR

9646_WHITEMANSSL

Small Unnamed Catchments and Direct Rainfall #5

Exhibit 19.d
Boundary Condition Inflows
Braided Geographic Reach Tributaries
(RM 160.1 to RM 168)

Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Note: Hydrographs shown in this figure are of USGS gage data.

Minimum flow applied at NF (7.45 cfs) and/or SF (3.17 cfs)

USGS Gage 12413000 - North Fork at Enaville, 15 min.

USGS Gage 12413470 - South Fork at Pinehurst, 15 min.

Exhibit 19.e

Boundary Condition Inflows: Upstream

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

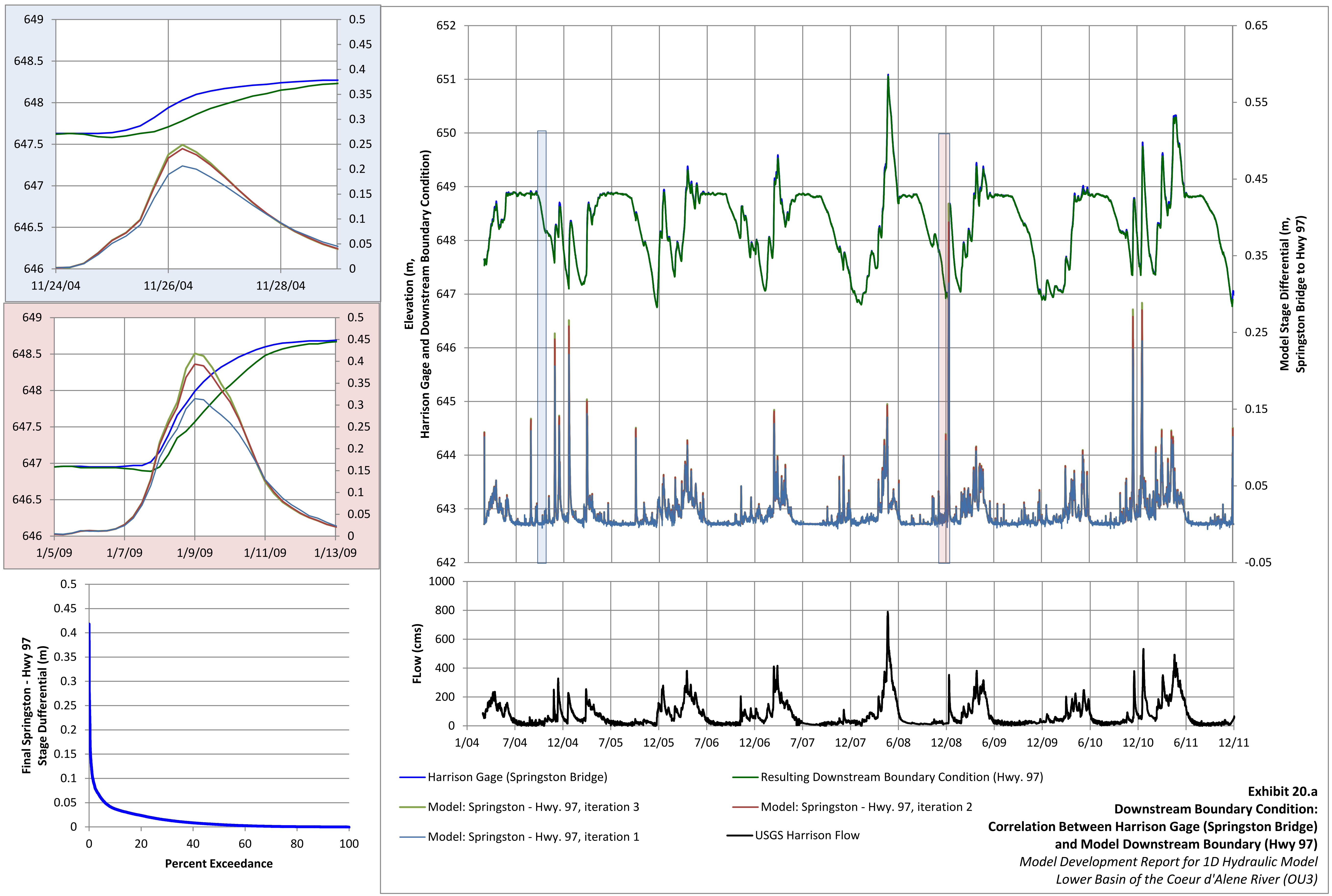
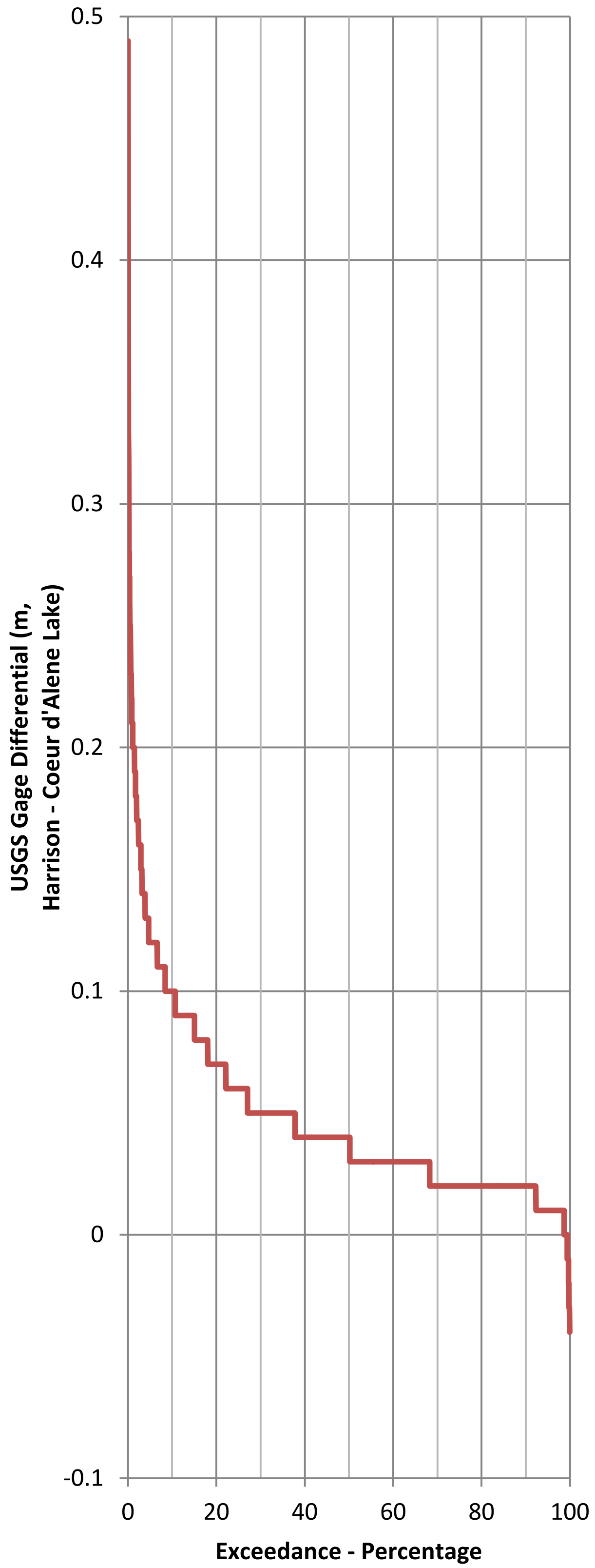


Exhibit 20.a
Downstream Boundary Condition:
Correlation Between Harrison Gage (Springston Bridge)
and Model Downstream Boundary (Hwy 97)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



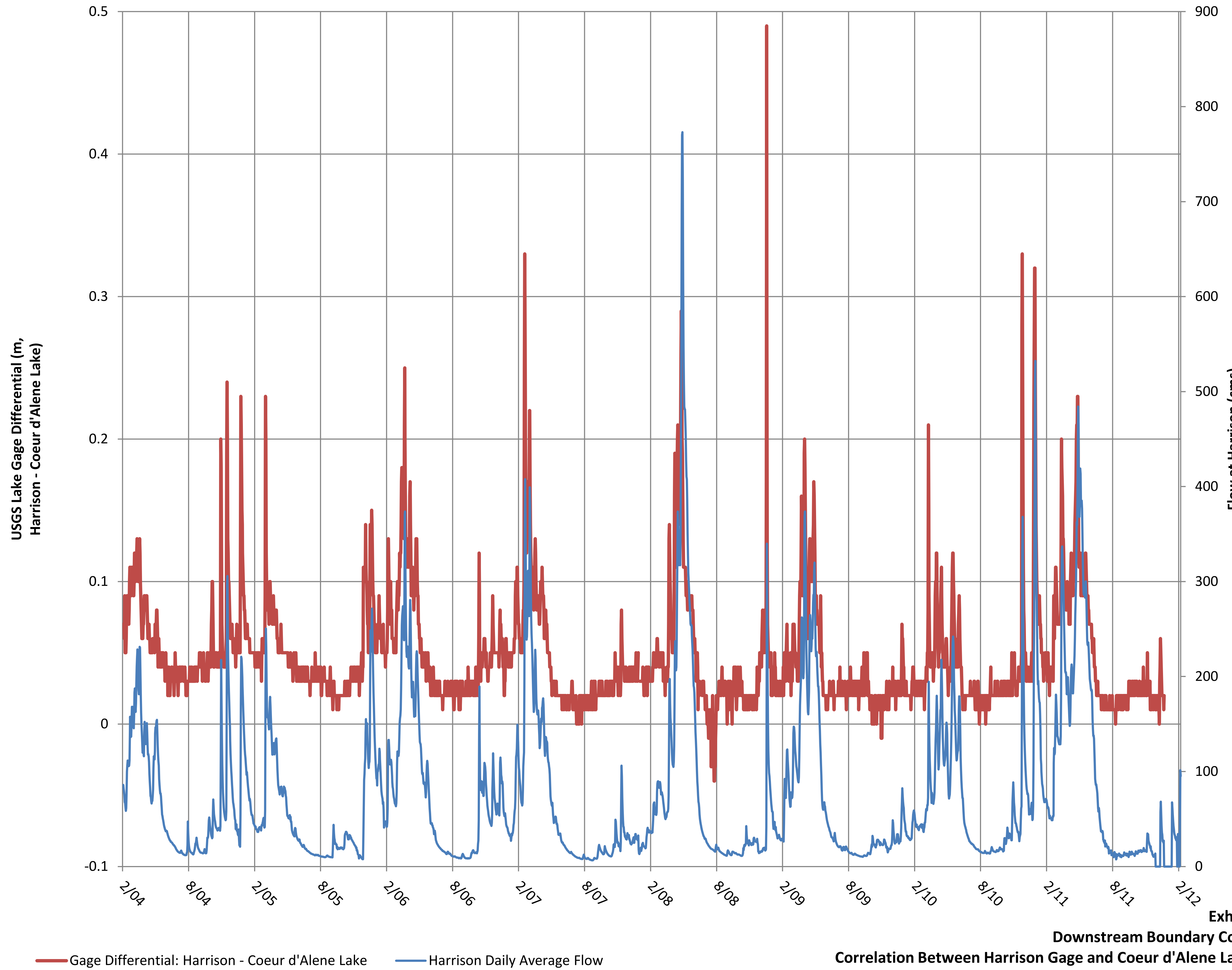


Exhibit 20.b
Downstream Boundary Condition:
Correlation Between Harrison Gage and Coeur d'Alene Lake Gage
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

EXHIBIT 21. INITIAL CONDITION SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Model Element	Initial Condition
Flow Conditions (cms)	
Blessing Slough 3233.648	9
Braided Upstream 57549.96	23
Braided South 2231.136	23
Braided North 55994.61	8
Meander 54194.36	32
Meander 43737.29	41
Meander 32979.66	46
Meander 19957.74	50.3
North Fork 646.9193	21
South Fork 486.3487	4
Storage Area Conditions (m NAVD88)	
1238 Lane Marsh 2	649.94
1239 Swan Lake 2	649.5
1240 Blue Lake	648
1241 Black Lake 2	648.1
1242 Cave Lake	648
1243 Medicine Lake 2	648.2
1244 Thompson Lake	648.11
1245 Anderson Lake	648.14
1246 Bare Marsh	649.12
1247 Skeel Gulch	651.2
1248 Upper Marsh 1	650
1249 Canyon Marsh	649.3
1250 Upper Marsh 2	649.83
1251 Orling Slough	650
1252 Bull Run Lake 1	650.11
1253 Porter Slough	646.04
1254 Bull Run Lake 2	648.9
1255 Black Rock Slough	648.65
1256 Strobl Field	648.74

EXHIBIT 21. INITIAL CONDITION SUMMARY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Model Element	Initial Condition
1257 Strobl Marsh	648.52
1258 Lane Marsh 1	649.95
1259 Moffit Slough	648.18
1260 Campbell Marsh	648.2
1261 Killarney Lake	648.2
1262 Medicine Lake 3	648.17
1263 Robinson Creek Marsh	648.4
1264 Medicine Lake 4	648.13
1265 Swan Lake 1	648.2
1266 Black Lake 1	647.29
1267 Lamb Peak 1	648.55
1268 Lamb Peak 2	649.3
9645 Mission Slough	648.26
9646 Whitemans Slough	652.96
9647 Dudley Marsh	649.02
9648 South Cataldo	652.33
9651 Rose Lake	644.52

EXHIBIT 22. MODEL STABILITY AND CALCULATION TOLERANCES
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Unsteady Flow Option	Value	Notes
Theta [implicit weighting factor] (0.6 – 1.0)	0.8	Lower values give most accurate solution to equations; higher values provide greatest stability.
Water surface calculation tolerance (m)	0.01	Lower values give most accurate solution to equations; higher values provide greatest stability.
Storage area elevation tolerances (m)	0.02	Lower values give most accurate solution to equations; higher values provide greatest stability.
Maximum number of iterations (0 – 40)	20	Threshold at which model stops iterating equations. If solution not within tolerances (set above), model reports the elevation difference.
Lateral structure flow stability factor (1.0 – 3.0)	2.0	Lower values give most accurate solution to equations; higher values provide greatest stability.
Weir flow submergence decay exponent (1.0 – 3.0)	1	Lower values give most accurate solution to equations; higher values provide greatest stability.

EXHIBIT 22. MODEL STABILITY AND CALCULATION TOLERANCES
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Unsteady Flow Option	Value	Notes
Maximum error in water surface solution (Abort Tolerance) (m)	1	Theshold at which model aborts (also known as "crashing"). Water surface errors between the calculation tolerance and the abort tolerance are reported in the fun file.

EXHIBIT 23. COMMONLY USED MODEL OUTPUT PARAMETERS
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Model Element	Commonly Used Model Output Parameters
Cross Section	Water surface elevation (m), total flow (Q, cms), channel velocity (m/s), overbank flow (Q, cms), overbank velocity (m/s), flow area (m^2)
Storage Area	Stage (m), net inflow (Q, cms)
Storage Area Connection	Headwater stage (m), tailwater stage (m), flow (Q, cms)
Lateral Structure	Upstream headwater stage (m), downstream headwater stage (m), tailwater stage (m), upstream headwater flow (Q, cms), downstream headwater flow (Q, cms), flow leaving [river, across lateral structure] (Q, cms)

EXHIBIT 24. CALIBRATION DATA AVAILABILITY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Gage ID	Gage Name	Period of Record	River Mile	Associated Model Element	Notes
USGS 12413860	COEUR D ALENE RIVER NR HARRISON ID	3/1/04 to Present[a]	134.5	XS 2972.734	
USGS 12413500	COEUR D ALENE RIVER NR CATALDO ID	10/1/86 to Present[a]	163.2	XS 49481.97	
LC-WL-01-R	Dudley-R	4/14/10 – Present[b]	156.1	XS 38064.8	
LC-WL-02-R	Rose Lake-L	11/20/11 – Present		SA 9651	Original logger, installed 4/14/10, destroyed prior to survey.
LC-WL-03-R	Black Rock Trailhead-R	4/14/10 – Present[b]	150.2	XS 28436.03	
LC-WL-04-L	Killarney Lake-L	4/14/10 – Present[b]	146.6	SA 1261	Moved on 11/14/11
LC-WL-04-R	Killarney Lake Outlet-R	4/14/10 – Present[b]	146.6	XS 22693.5	
LC-WL-05-L	Medicine Lake-L	4/14/10 – Present[b]	143.4	SA 1264	

EXHIBIT 24. CALIBRATION DATA AVAILABILITY
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Gage ID	Gage Name	Period of Record	River Mile	Associated Model Element	Notes
LC-WL-05-R	Medicine Lake Outlet-R	4/14/10 – Present[b]	143.4	XS 17468.38	Moved on 1/10/11
LC-WL-06-L	Cave Lake	4/14/10 – Present[b]	141.1	SA 1242	
LC-WL-07-L	Swan Lake-L	4/14/10 – Present[b]	140.1	SA 1265	
LC-WL-07-R	Swan Lake Outlet-R	4/14/10 – Present[b]	140.1	XS 12123.91	
LC-WL-08-L	Blue Lake-L	4/14/10 – Present[b]	137	SA 1240	
LC-WL-08-R	Blue Lake Outlet-R	4/14/10 – Present[b]	137	XS 7074.92	
LC-WL-09-L	Thompson Lake-L	4/14/10 – Present[b]	135.2	SA 1244	
LC-WL-09-R	Thompson Lake Outlet-R	4/14/10 – Present[b]	135.2	XS 4095.95	
LC-WL-10-R	Below SF/NF Confluence-R	1/17/12 – Present[c]	167.8	XS 57269.68	
LC-WL-11-R	Above Cataldo Dredge Pool-R	1/17/12 – Present[c]	160.4	XS 44957.04	
LC-WL-12-R	Below Dudley/Above Bull Run-R	1/17/12 – Present[c]	154.7	XS 35737.13	
LC-WL-13-R	Below Bull Run-R	1/17/12 – Present[c]	152.5	XS 32299.19	

[a] Data at the USGS gages are continuously recorded. Availability of data for project use is subject to retrieval from the USGS. The most recent data retrieval, and thus the end date of available data is February 14, 2012.

[b] At the time this report was prepared these loggers were still installed and assumed to be operational and recording data. Availability of data is limited to field retrieval of data. The most recent data retrieval, and thus the end date of available data is January 1, 2011.

[c] At the time this report was prepared these loggers were still installed and assumed to be operational and recording data. Availability of data is limited to field retrieval of data. At this point, data from these loggers has not yet been retrieved.

SA = Storage Area, XS = Cross Section, -R = River Logger, -L = Lake Logger

EXHIBIT 25. CALIBRATION AND VALIDATION EVENTS
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Date Range	Duration	Peak Cataldo Flow [Date], Peak Harrison Flow [Date] (cms)	Recurrence Interval (instan-taneous flow rate)	Coeur d'Alene Lake Level at start of event, at end of event (m NAVD 88)	Event Characteristics	Notes
Calibration Period						
3/29/10 to	115 days	260.23 [6/5/10 21:45], 254.59 [6/6/10 11:30]	> 1.01 year	647.22, 648.84	Small spring runoff with multiple peaks;	A series of 6 distinct smaller

Date Range	Duration	Peak Cataldo Flow [Date], Peak Harrison Flow [Date] (cms)	Recurrence Interval (instan-taneous flow rate)	Coeur d'Alene Lake Level at start of event, at end of event (m NAVD 88)	Event Characteristics	Notes
7/22/10					started at low lake level. Acted as lake filling event, filled lake by 1.62 m.	events, ranging from 10 to 20 days each.
12/12/10 to 12/23/10	11 days	537.84 [12/14/10 17:15], 387.69 [12/15/10 7:45]	> 1.25 year	647.42, 647.42	Moderate flashy winter runoff at low lake level.	
1/13/11 to 1/24/11	11 days	934.46 [1/17/11 22:30], 532.36* [1/19/11]	> 5 years	647.42, 647.36	High flashy winter runoff at low lake level.	
3/29/11 to 4/11/11	13 days	495.52 [4/1/11 10:30], 353.76 [4/3/11 8:15]	> 1.25 year	648.26, 648.49	Moderate spring event at moderate lake level. Acted partially as lake filling event.	Preceded by about 20 days of slightly elevated flows.
5/2/11 to 7/23/11	82 days	662.35 [5/16/11 17:45], 521.03 [5/17/11 10:30]	> 2 years	648.65, 648.82	High spring runoff at high water level.	A long spring runoff event with more than 6 distinct peaks.
Validation Period						
12/28/11 to 1/6/12	9 days	73.63 [12/31/11 5:45] , 77.87 [12/31/11 8:00]	<1.01 years	646.82, 646.78	Small, short, winter runoff at low lake level	
1/29/12 to 2/6/12	8 days	60.02 [1/31/12 5:00], 74.19 [1/31/12 2:45]	<1.01 years	646.80, 646.99	Small, short, winter runoff at low lake level	
2/21/12 to 3/3/12	11 days	106.19 [2/23/12 6:45], 115.25 [2/23/12 19:30]	<1.01 years	646.96, 647.29	Small, short, winter runoff at low lake level	
3/15/12 to 3/23/12	8 days	427.58 [3/16/12 21:45], 302.99 [3/17/12, 21:15]	>1.25 years	647.73, 648.28	Medium spring event starting at low lake level. Acted partially as lake filling event.	
3/28/12 to 4/9/12	12 days	824.02 [3/31/12 10:30], 512.55 [3/31/12 6:45]	~5 years	648.70, 649.02	Large spring event at high lake level	

Date Range	Duration	Peak Cataldo Flow [Date], Peak Harrison Flow [Date] (cms)	Recurrence Interval (instan-taneous flow rate)	Coeur d'Alene Lake Level at start of event, at end of event (m NAVD 88)	Event Characteristics	Notes
4/16/12 to 5/28/12	42 days	753.21 [4/25/12 3:45], 634.30 [4/26/12 20:45]	>2 years	649.25, 648.71	Large spring event at high lake level.	
6/2/12 to 7/15/12	43 days	339.80 [7/7/12 7:45], 314.31 [7/10/12 23:30]	>1.11 years	648.71, 648.74	Medium spring event at high lake level.	

* 1*5-minute data is not available for flow at Harrison; mean daily flow is used instead.*

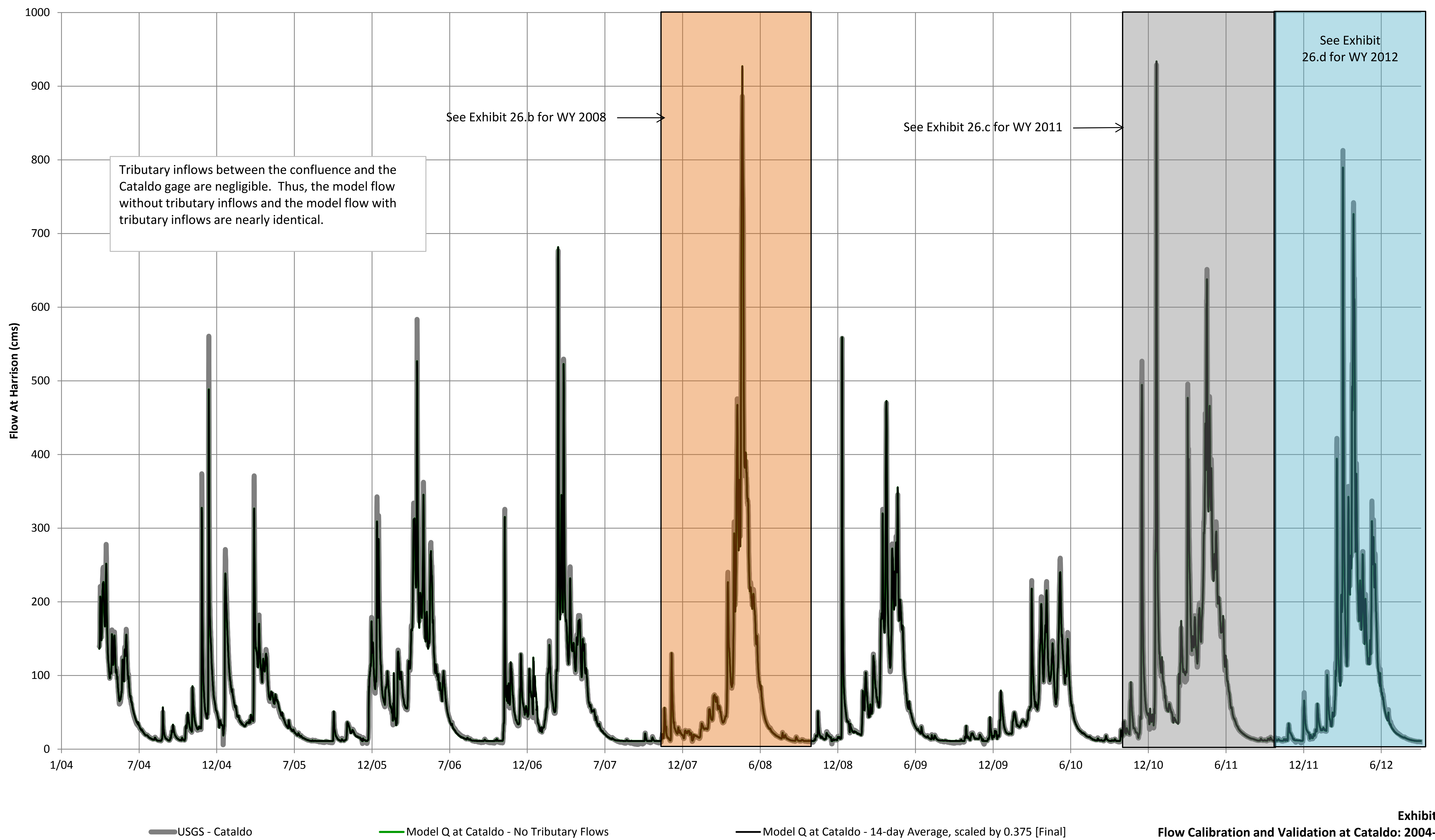


Exhibit 26.a
Flow Calibration and Validation at Cataldo: 2004-2012
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

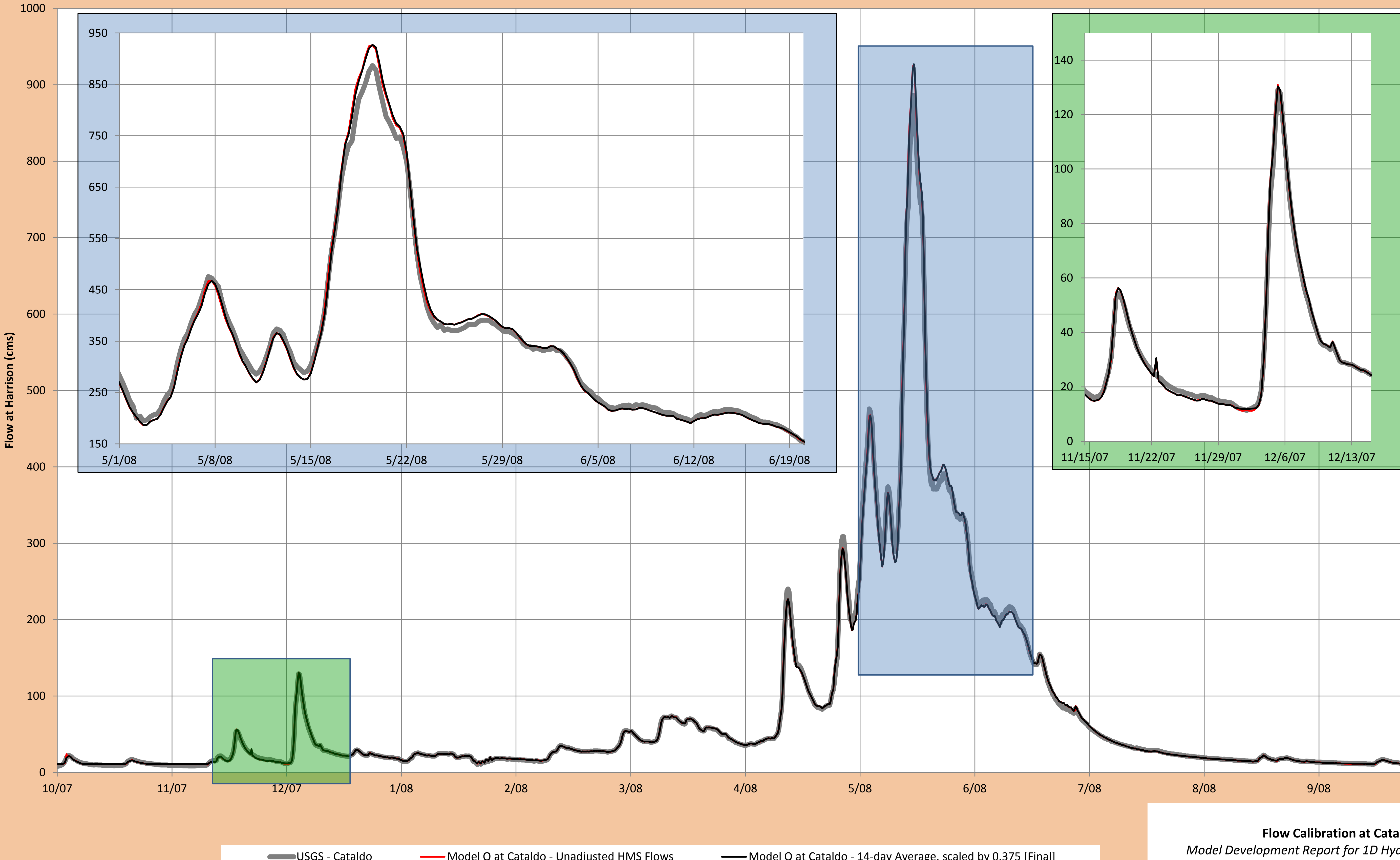


Exhibit 26.b
Flow Calibration at Cataldo: WY2008
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

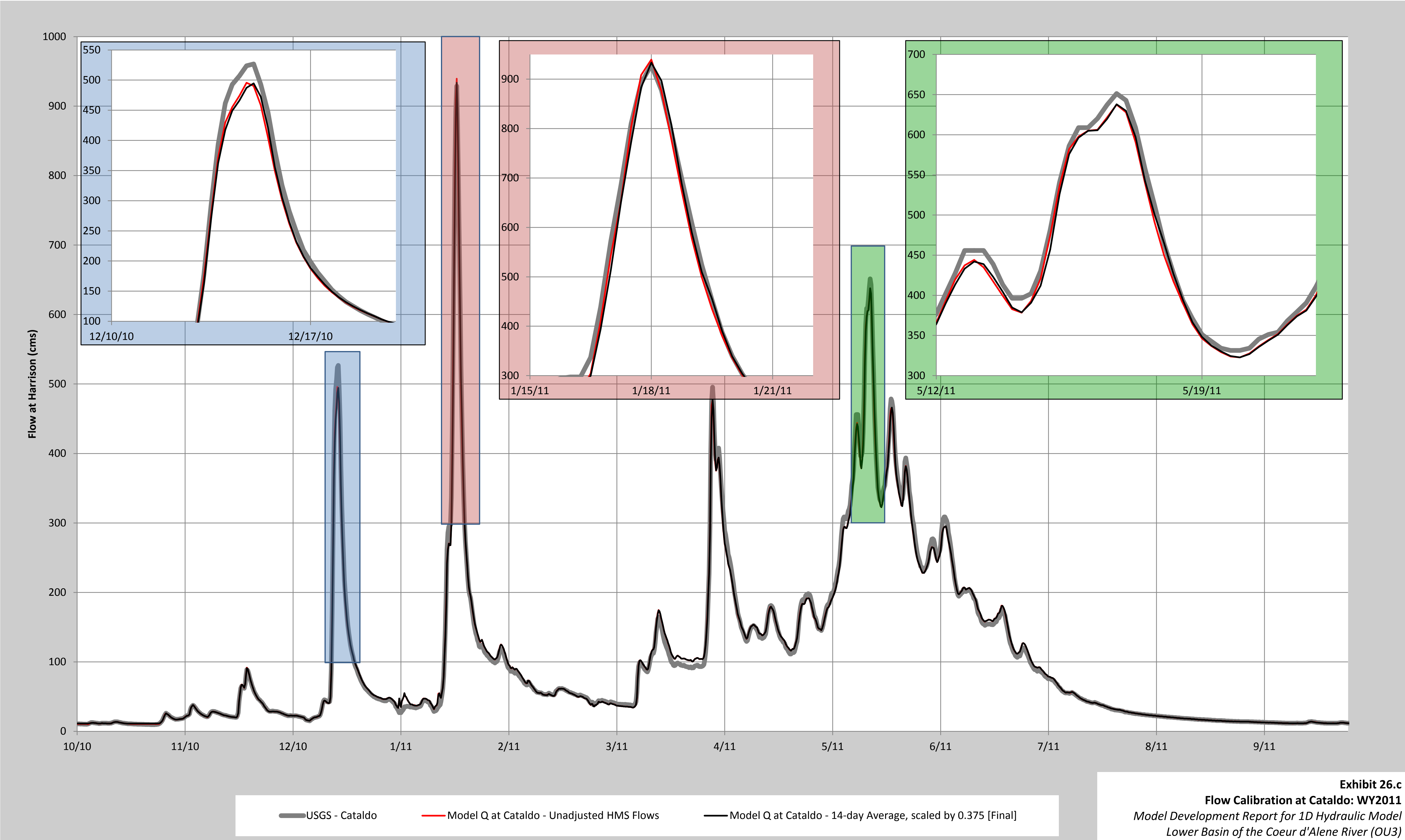


Exhibit 26.c
Flow Calibration at Cataldo: WY2011
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

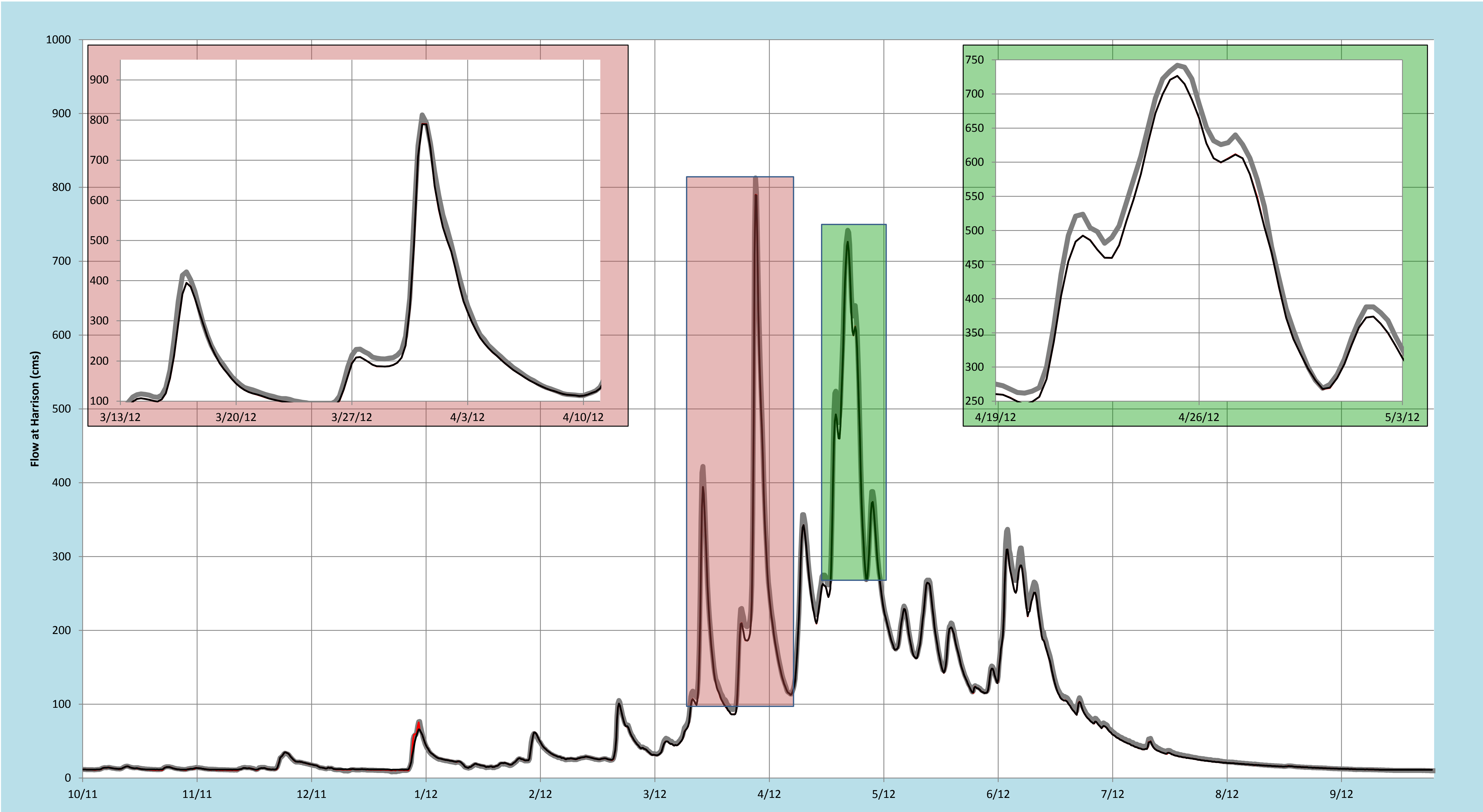
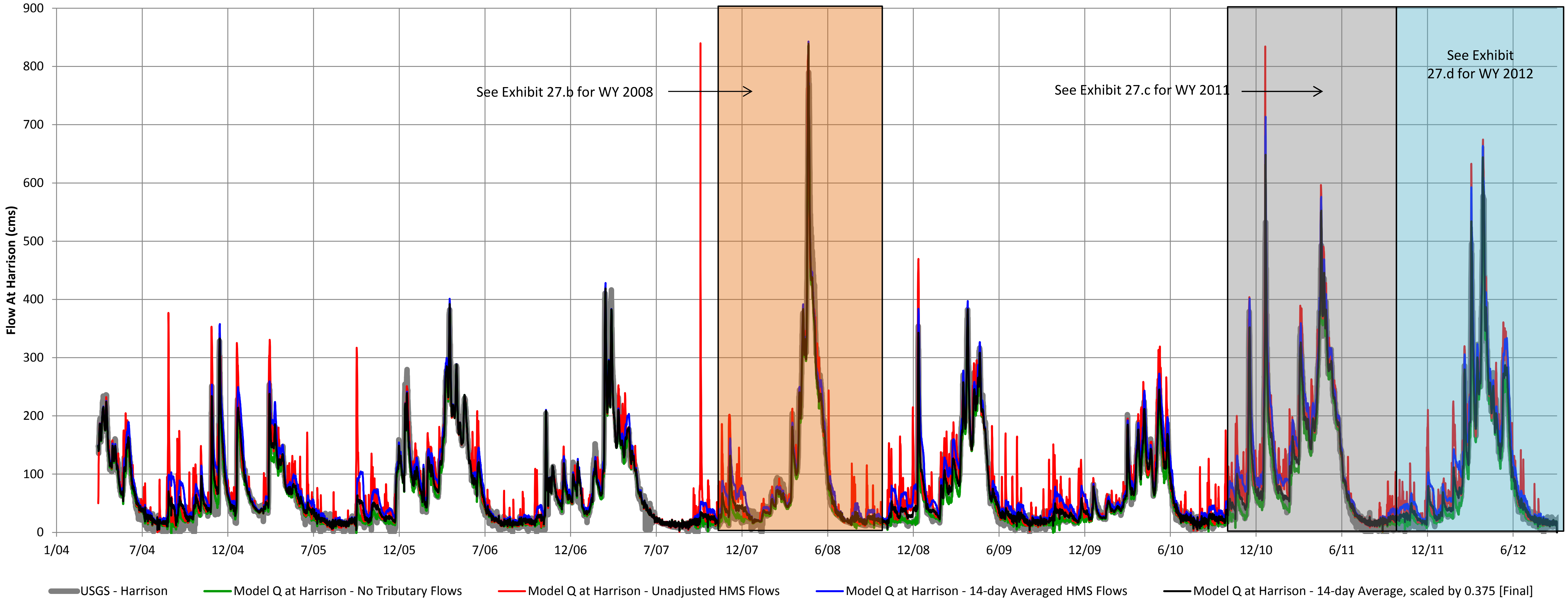


Exhibit 26.d
Flow Validation at Cataldo: WY2012
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



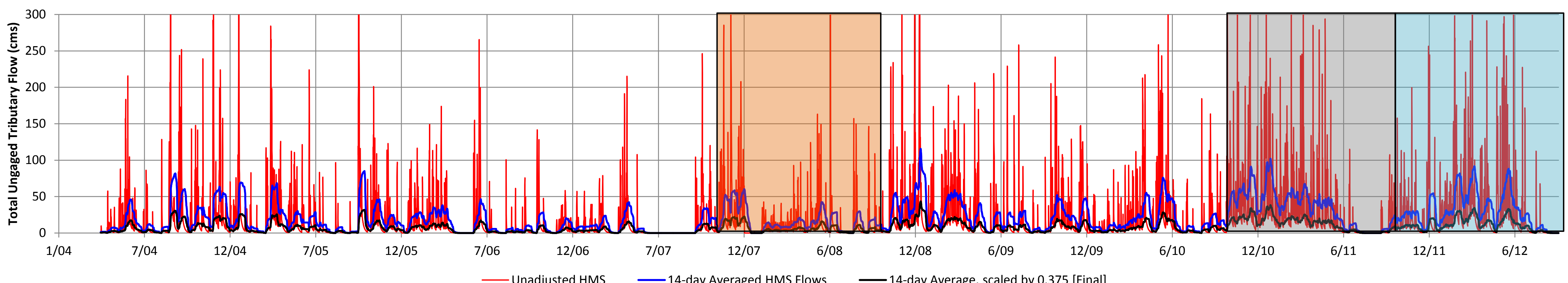


Exhibit 27.a
Flow Calibration and Validation at Harrison: 2004-2012
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

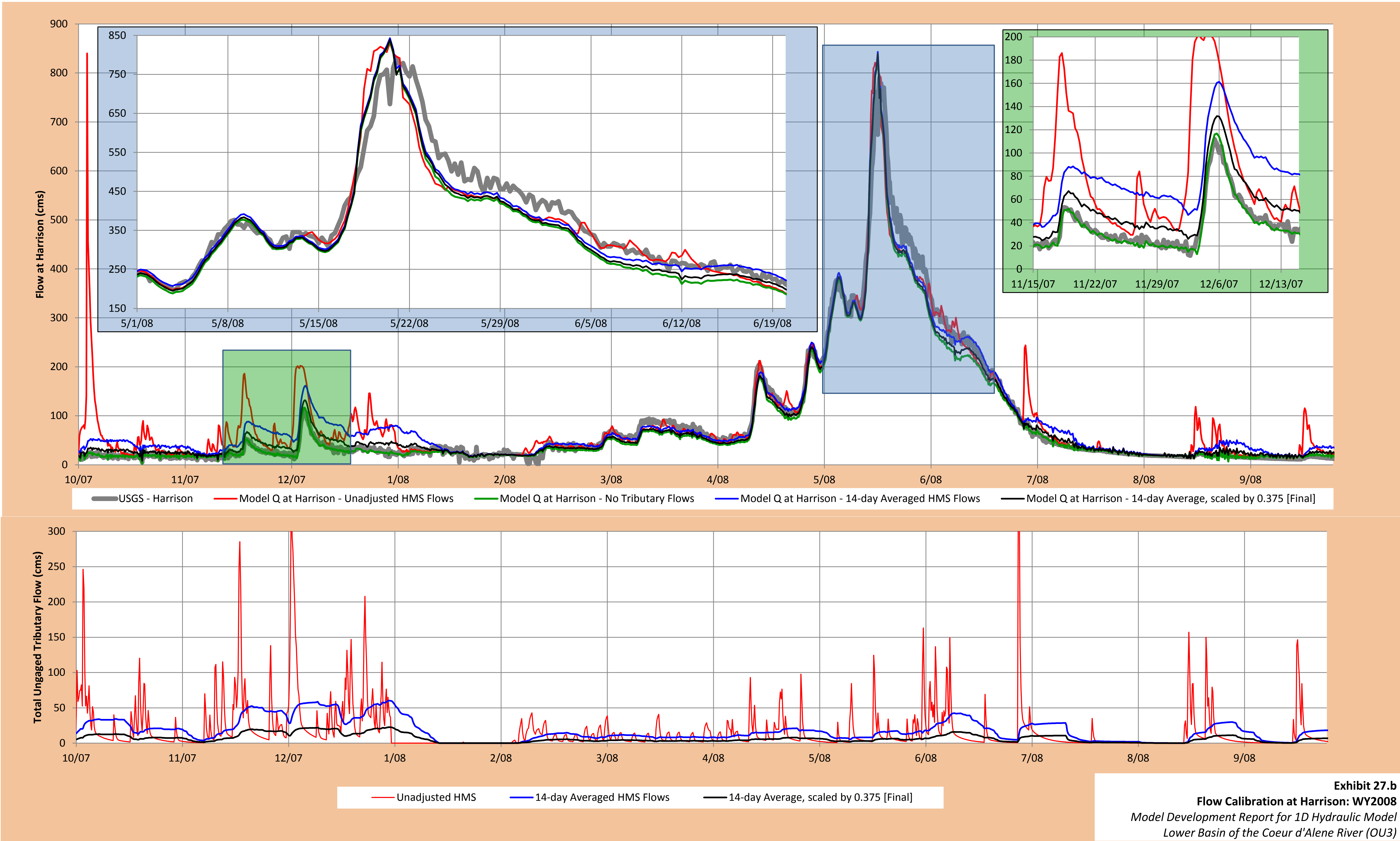
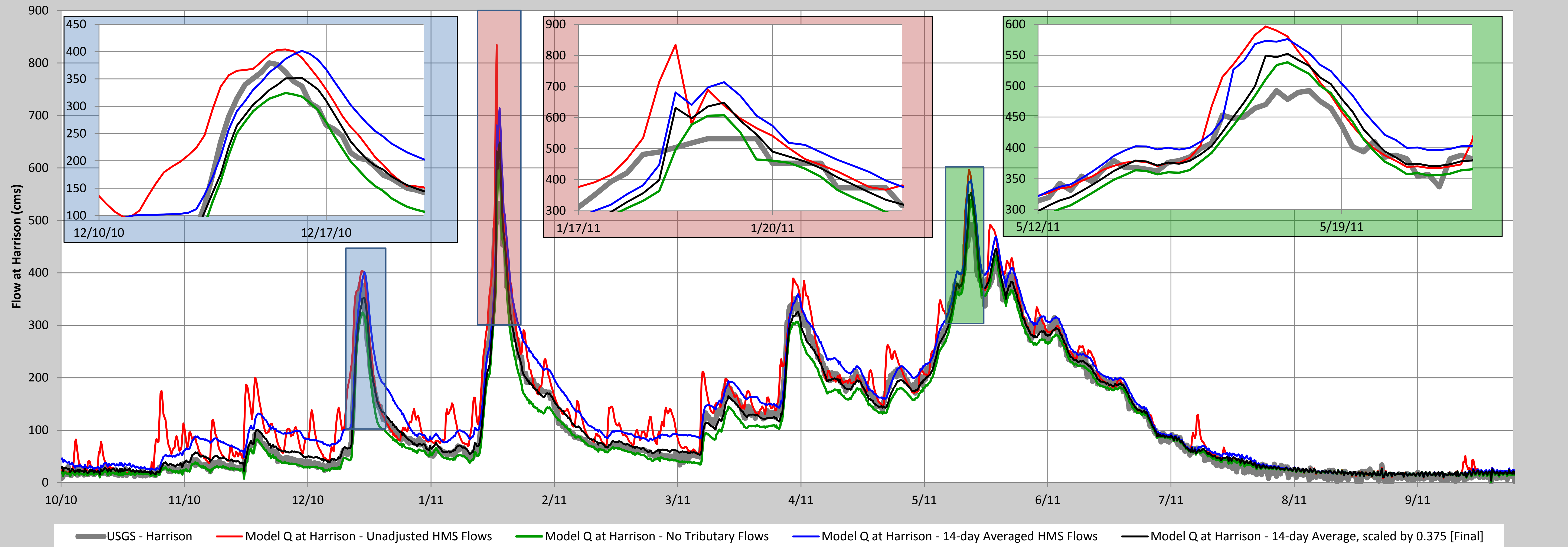


Exhibit 27.b
Flow Calibration at Harrison: WY2008
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



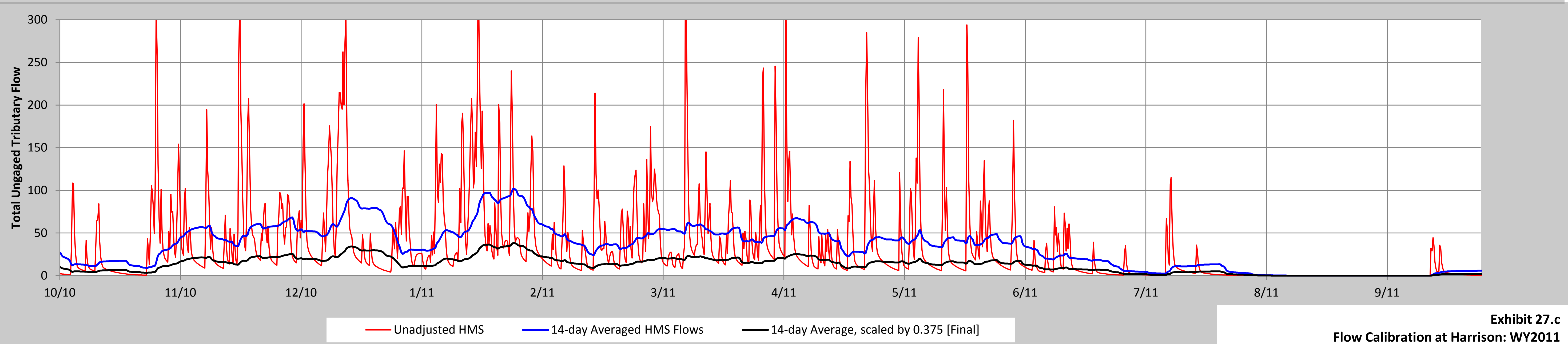
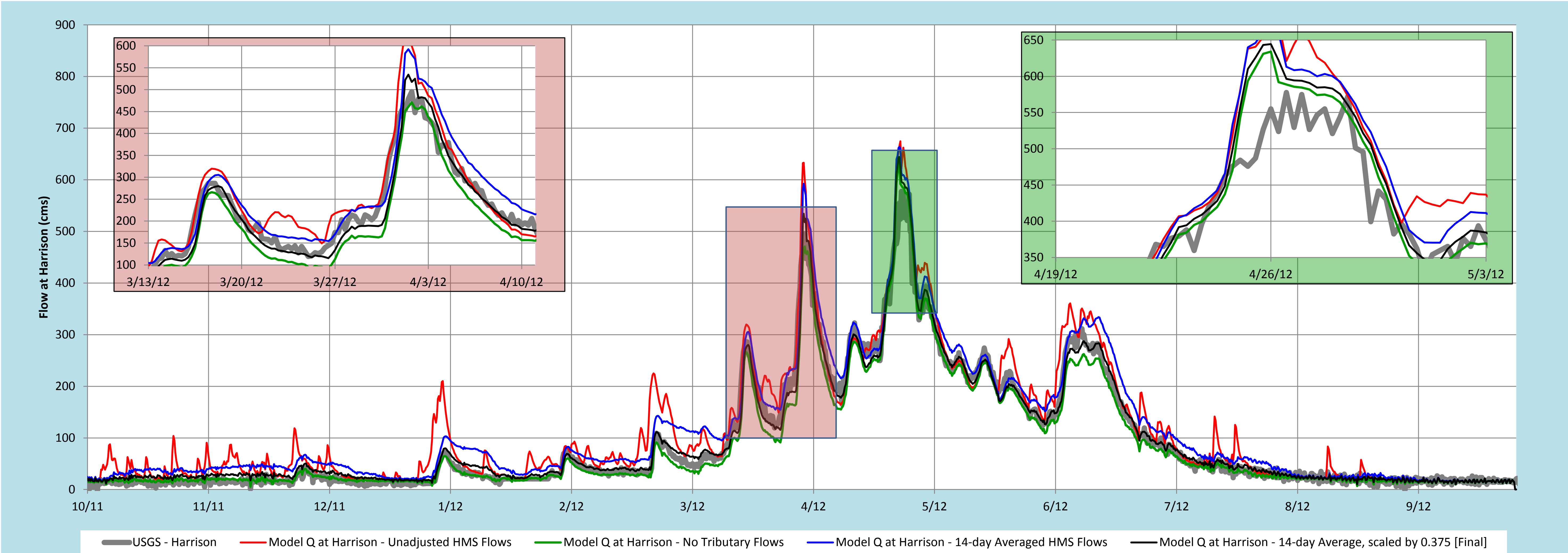


Exhibit 27.c

Flow Calibration at Harrison: WY2011

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)



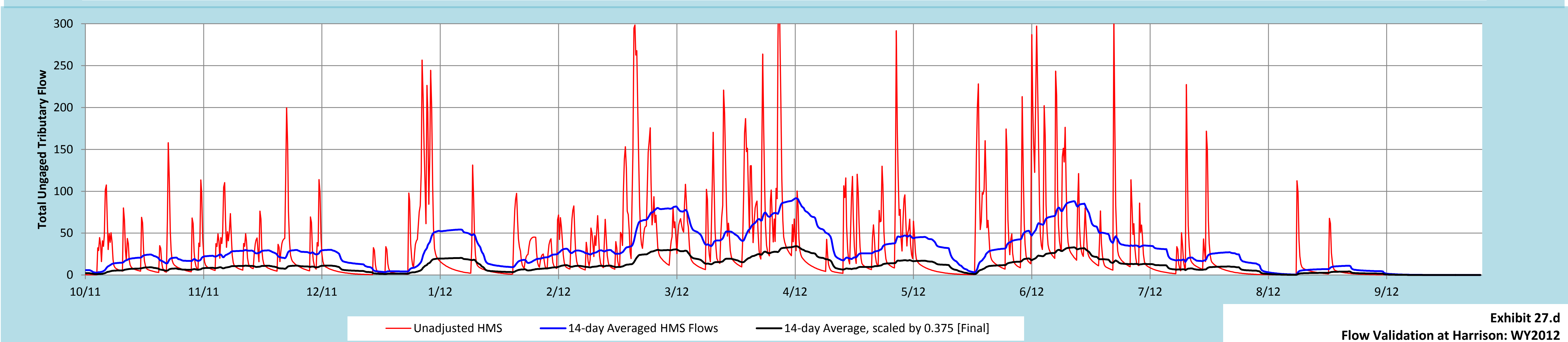


Exhibit 27.d
Flow Validation at Harrison: WY2012
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

EXHIBIT 28. ROUGHNESS COEFFICIENT FLOW SCALING FACTORS
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Flow	**Thompson Lake 4308 to 0**	**Blue Lake 7154 to 4462**	**Swan Lake 12310 to 7251**	**Medicine Lake 17541 to 12409**	**Killarney Lake 22820 to 17640**	**Black Rock 28497 to 22899**	**Below Bull Run 32493 to 28561**	**Above Bull Run 35876 to 32401**	**Dudley 383368 to 28561**	**Dredge Pool 45254 to 38453**	**Confluence 57550 to 45383**
0	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1	1.5	0.5	0.5
50	1.5		1.3	0.96		1.1	1.2	1.1	1.2	0.5	0.7
100		1	1		0.95			0.9	1	0.5	0.84
150				0.85		0.97	1				
200		0.8			1.22		1.05	1	1.06	0.53	0.86
250	1.38		0.97								
300				0.88	0.99	1.02	0.96	0.98	0.98	0.72	0.92
350		0.75									
400	1.28	0.68	0.95	0.76	1.18	0.98	1.16	0.88	0.9	0.72	0.96
475			1.36								
500	1.19	0.69	0.6	0.82	0.9		1.26	0.96	0.9	0.8	1.11
600	1.19	0.56	0.55	0.56		1.11	1.09				
650										0.76	1.09
700						0.59	1.25				
750								0.8	0.75	1	1.18
800	0.91	0.56	0.65	0.9	0.9	0.92	1.25				
1000								0.8	0.9	1	1.4
1500	0.91	0.5	0.65	0.9	0.9	0.92	1.25	0.8	0.8	1	1.2

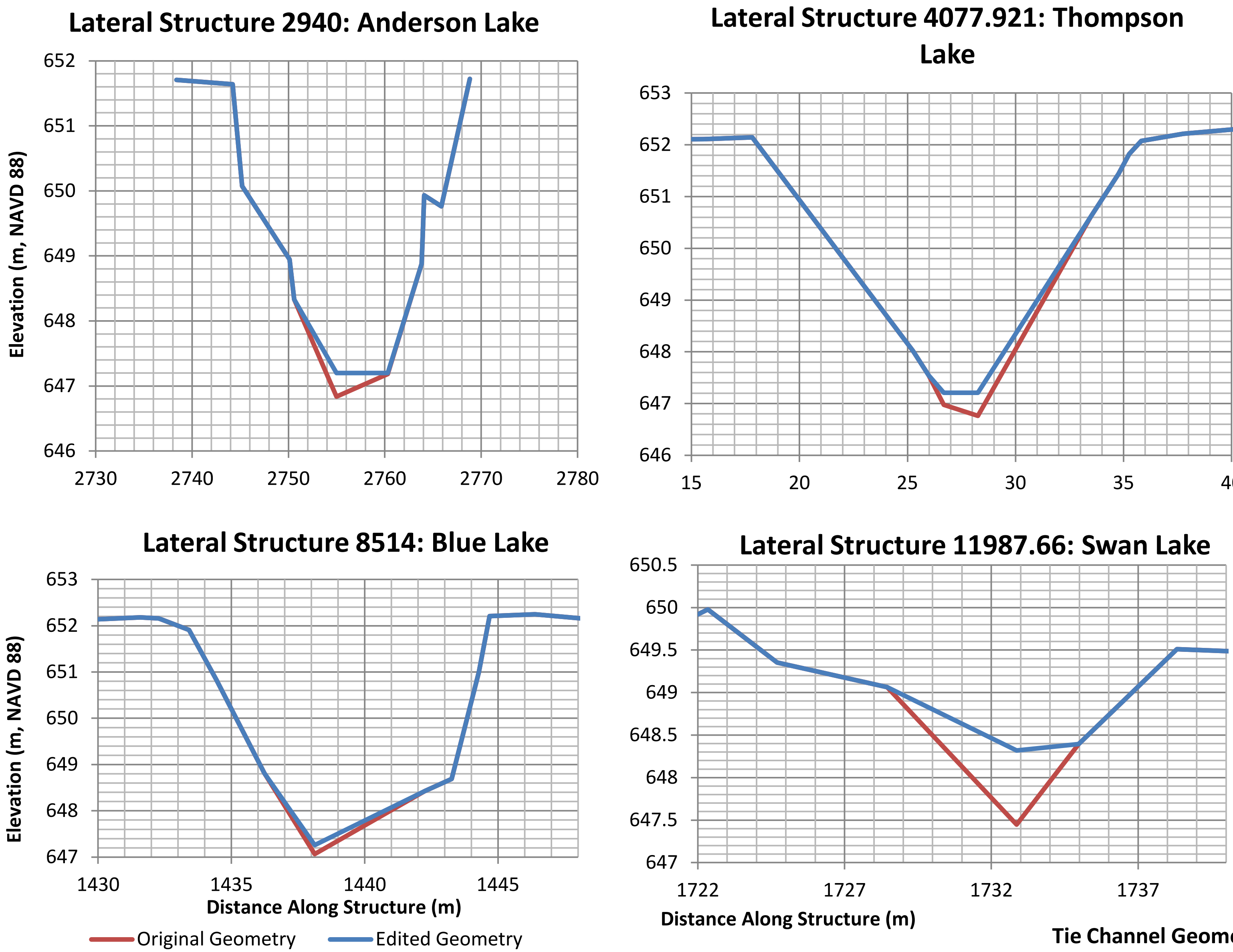


Exhibit 29.a

Tie Channel Geometry Changes

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

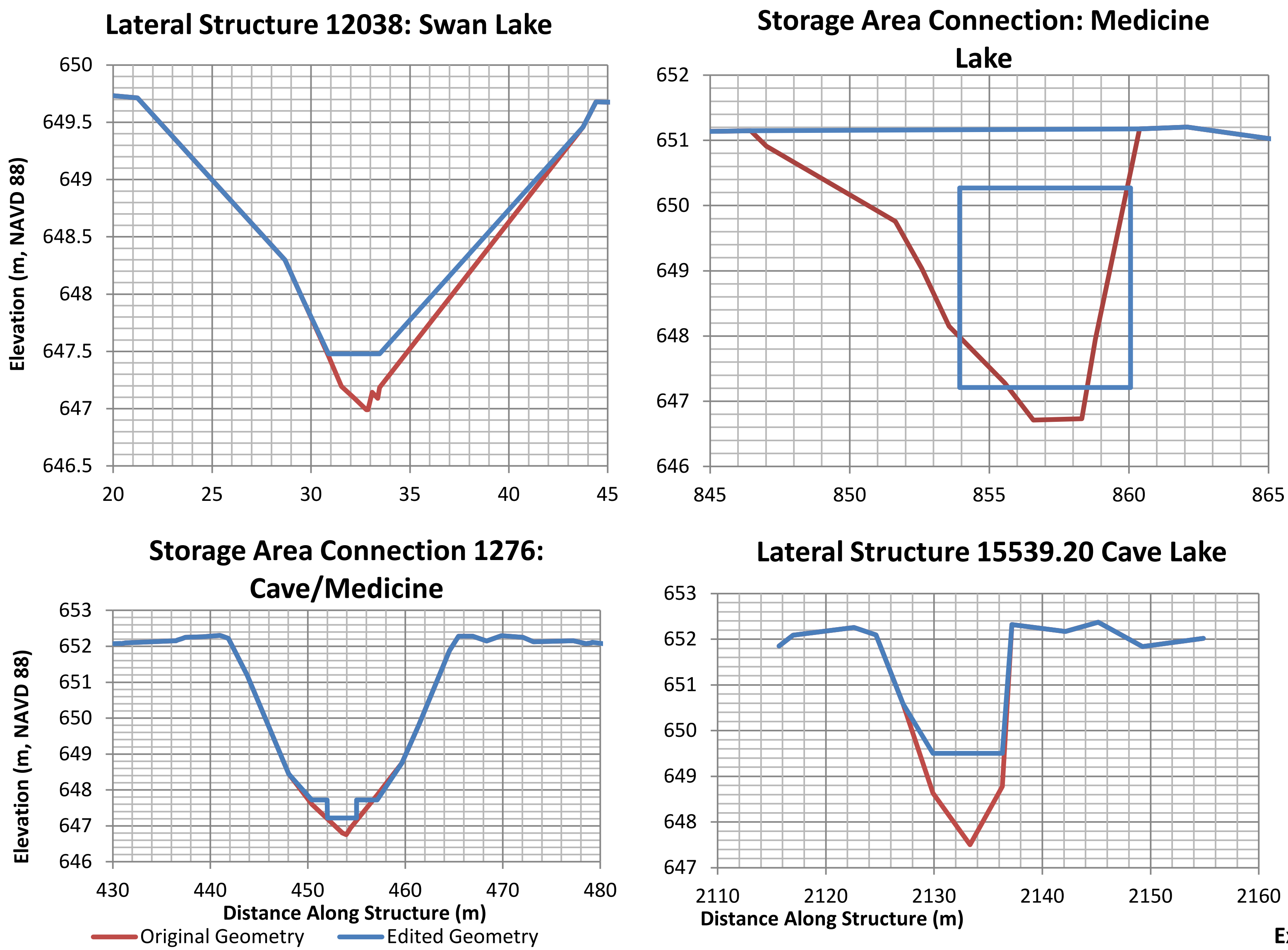


Exhibit 29.b
Tie Channel Geometry Changes
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

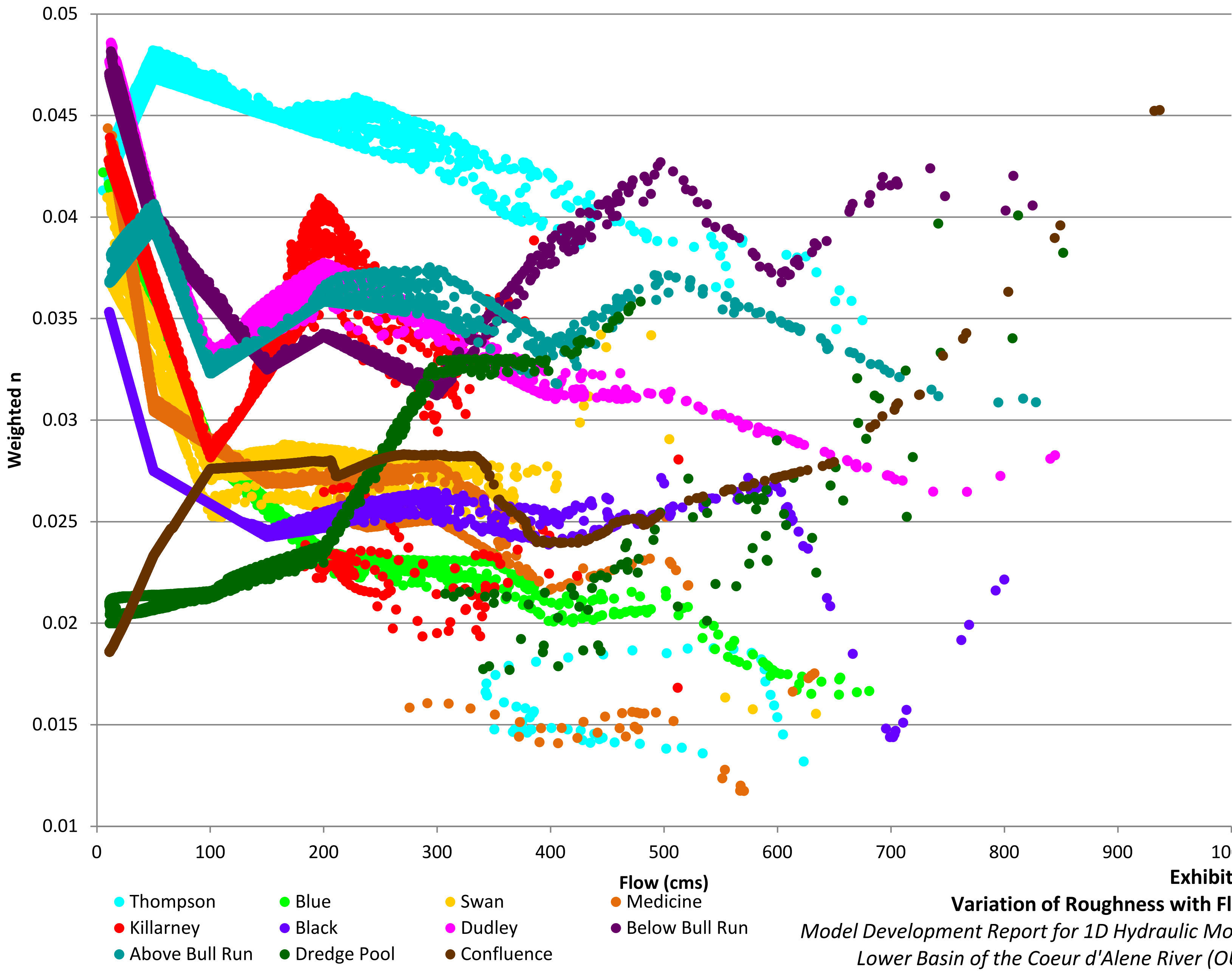


Exhibit 30

Variation of Roughness with Flow

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

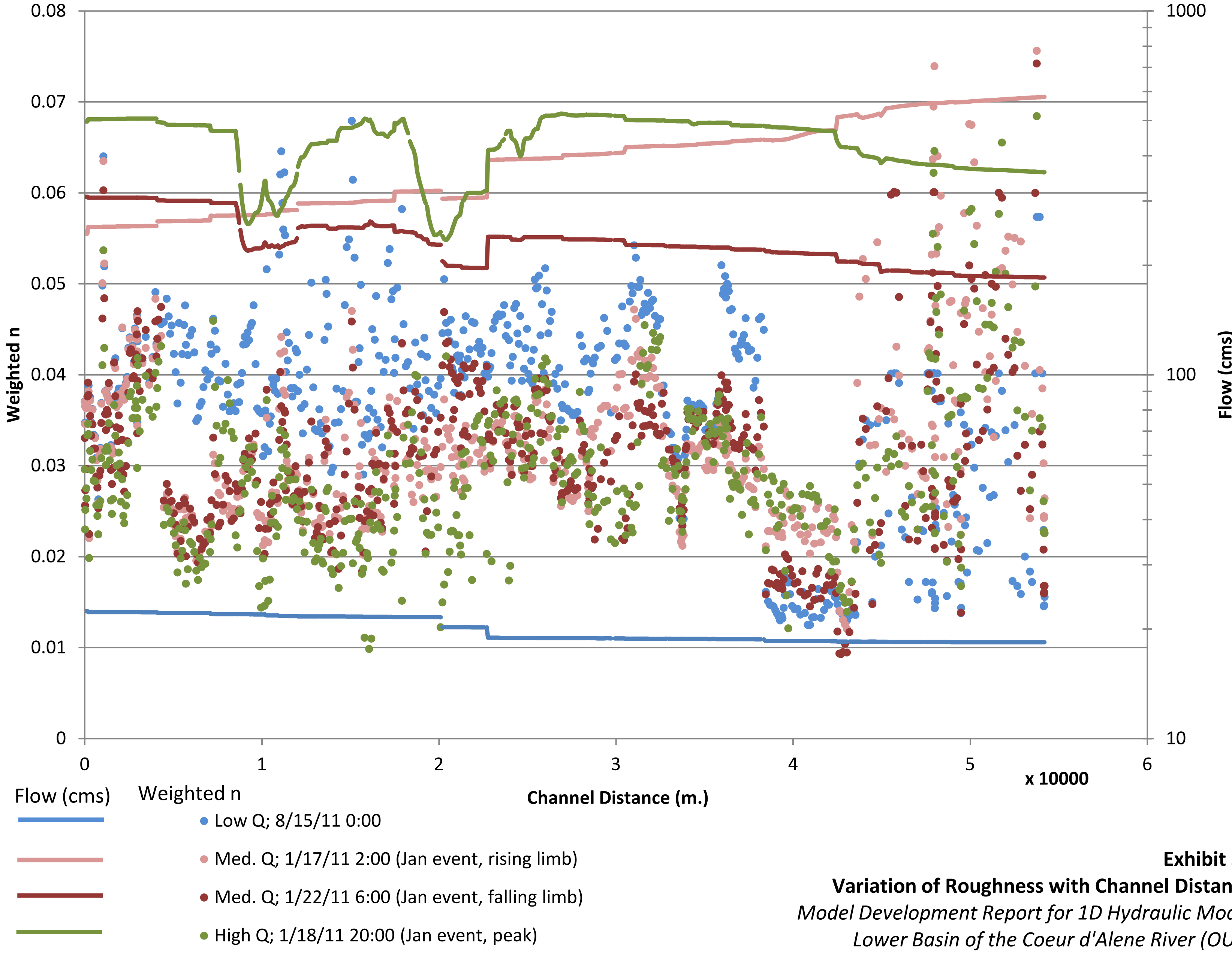


Exhibit 31
Variation of Roughness with Channel Distance
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

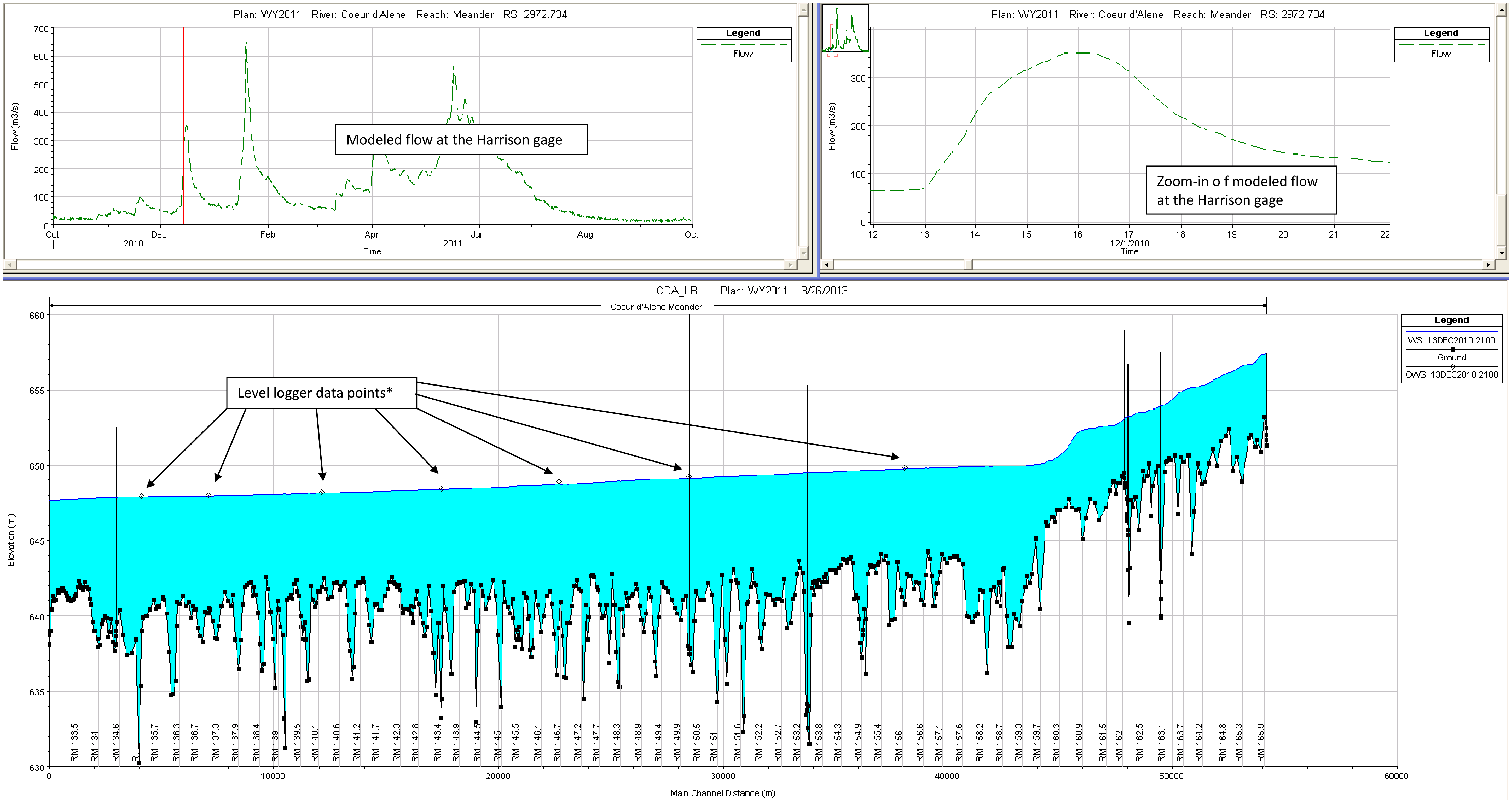


Exhibit 32.a.i. Modeled water surface elevation profile of the rising limb of the December 2010 event, including comparison with level logger data.

* Note: Level logger data datums are unadjusted. See Section 5.2.1 and Exhibit 16 for information on the adjustment of level logger datums.

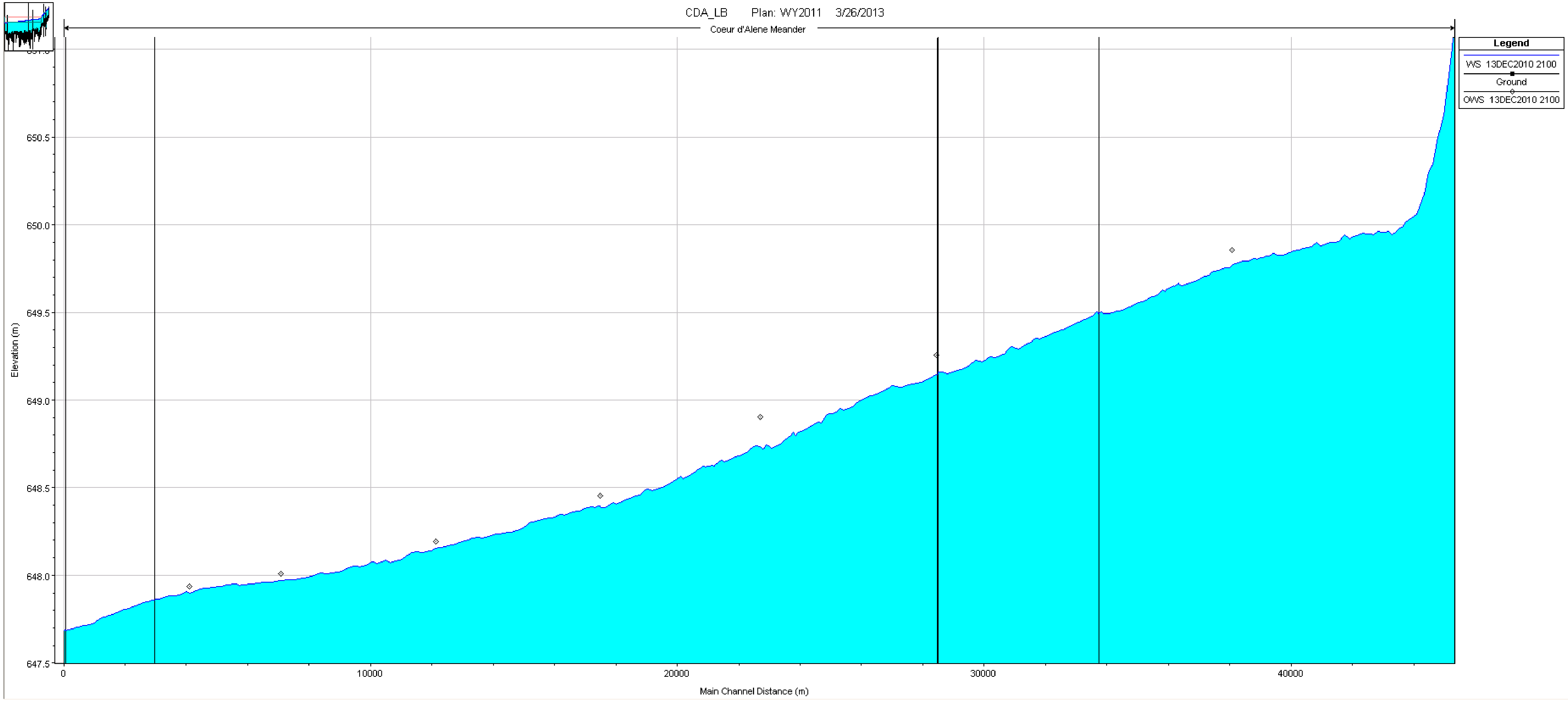


Exhibit 32.a.ii. Close-up of the modeled water surface elevation profile of the rising limb of the December 2010 event, including comparison with level logger data.

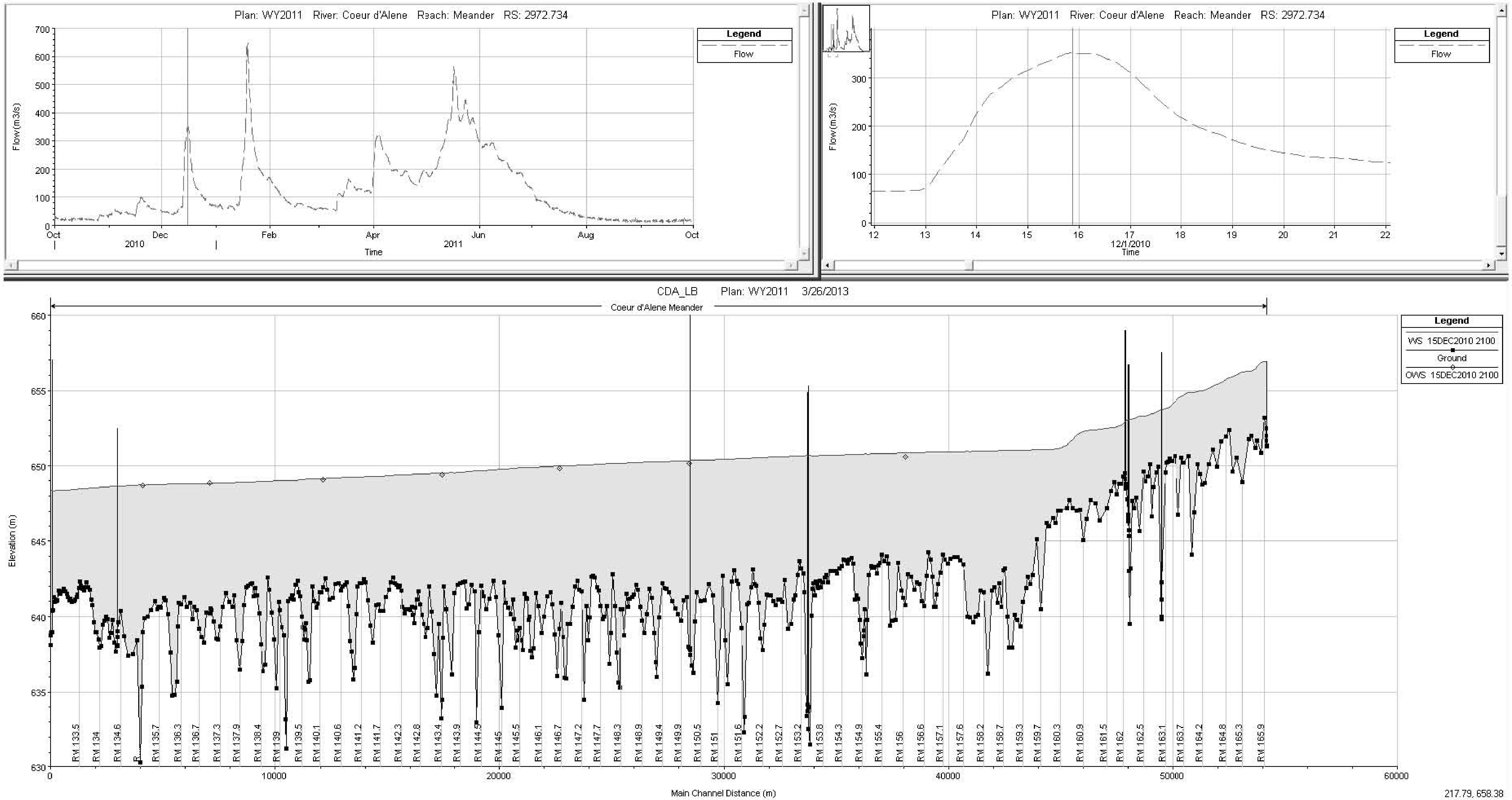


Exhibit 32.b.i. Modeled water surface elevation profile of the peak of the December 2010 event, including comparison with level logger data.

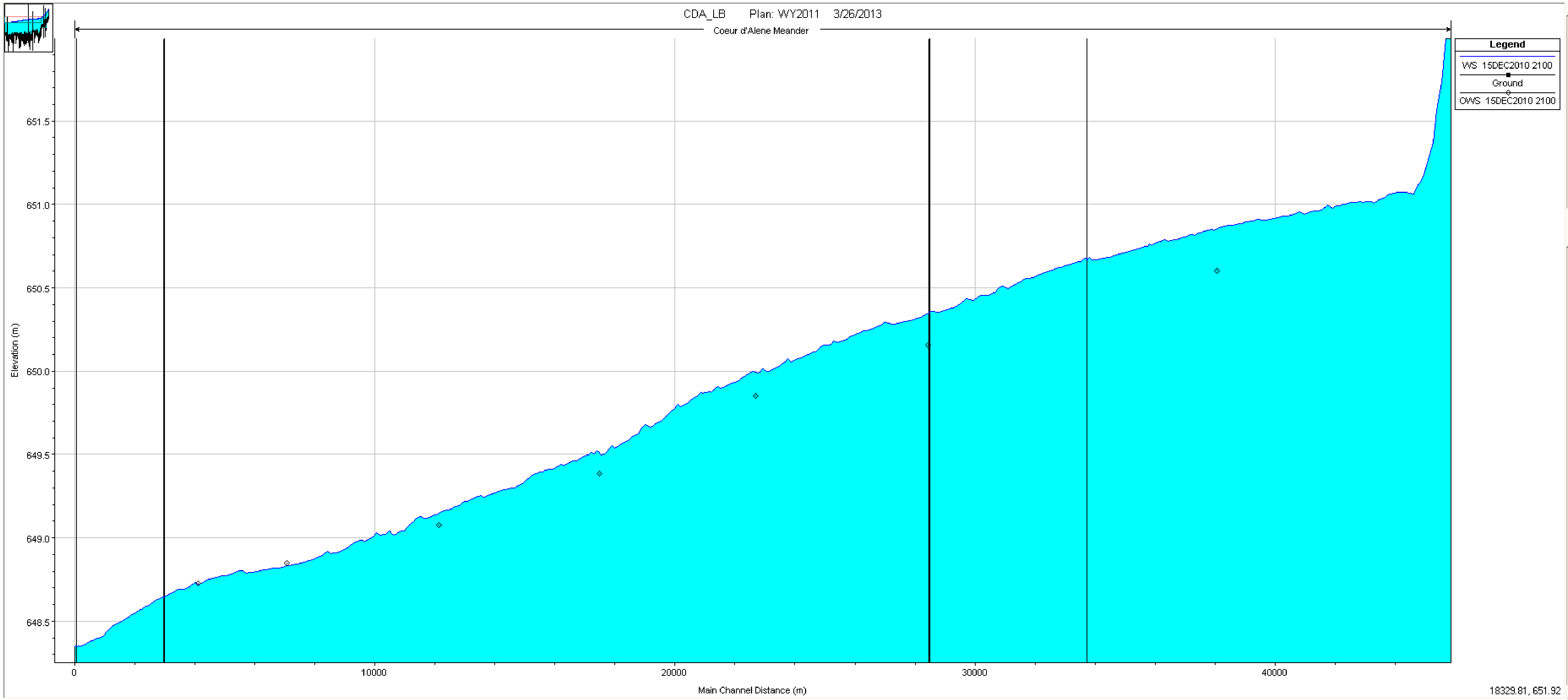


Exhibit 32.b.ii. Close-up of the modeled water surface elevation profile of the peak of the December 2010 event, including comparison with level logger data.

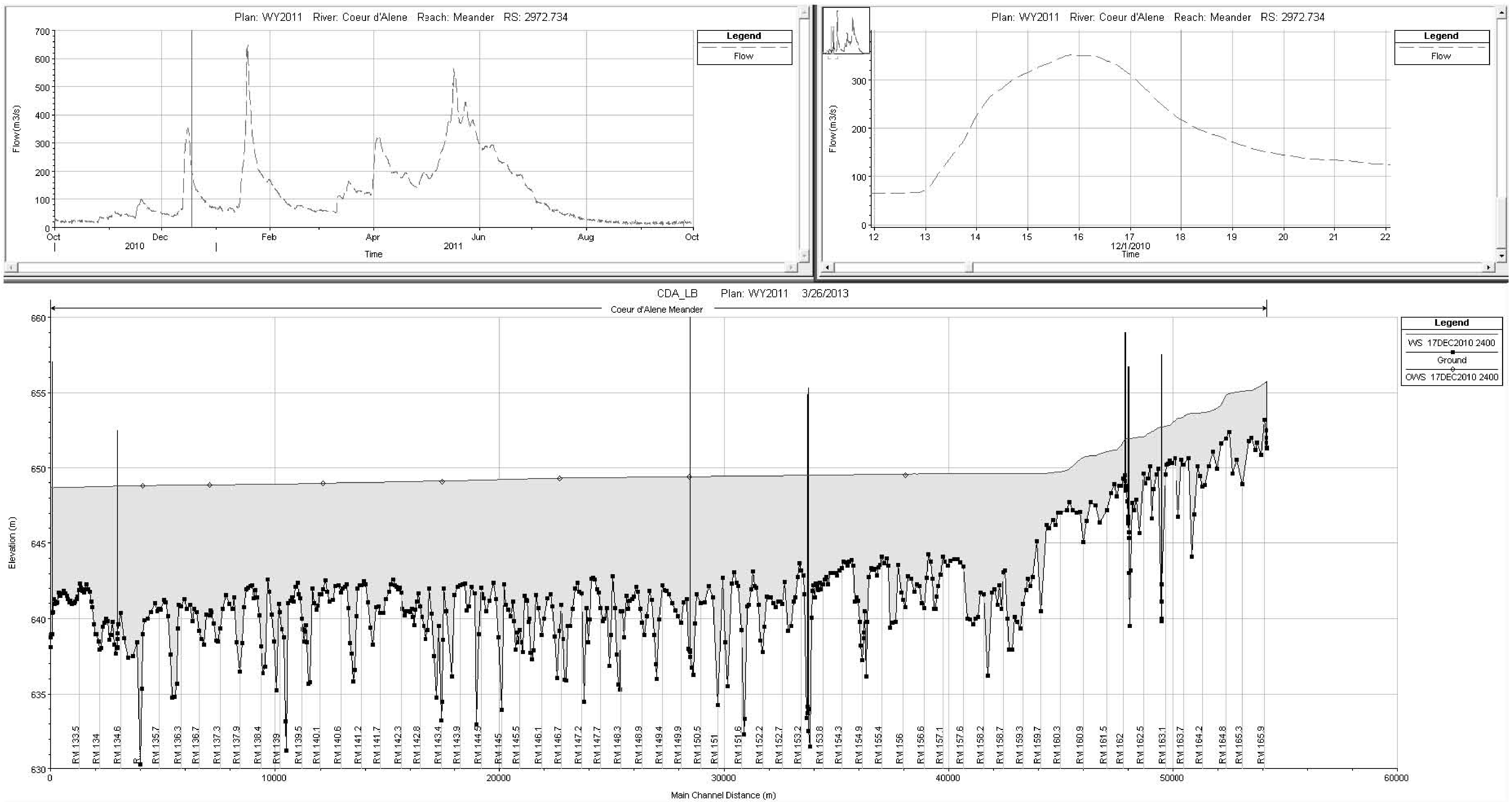


Exhibit 32.c.i. Modeled water surface elevation profile of the falling limb of the December 2010 event, including comparison with level logger data.

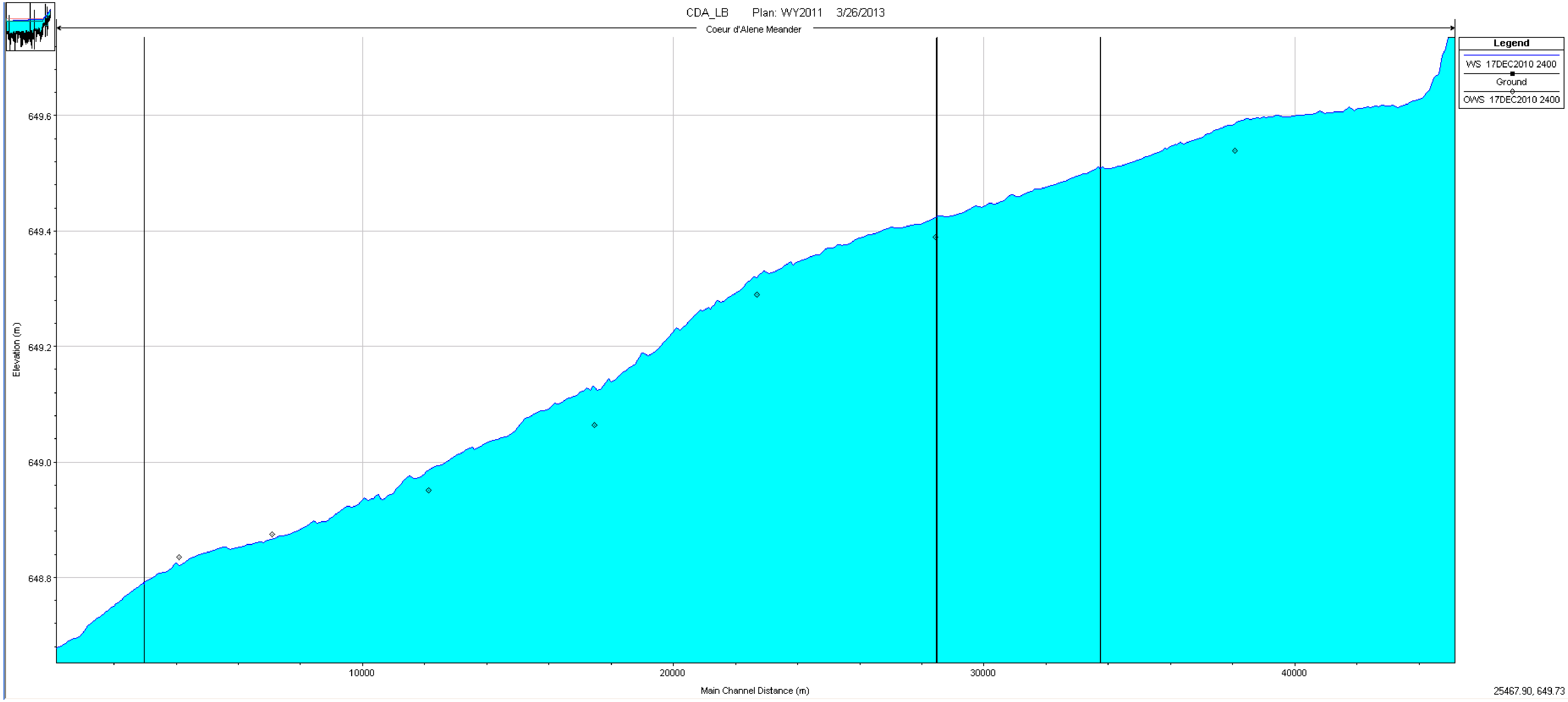


Exhibit 32.c.ii. Close-up of the modeled water surface elevation profile of the falling limb of the December 2010 event, including comparison with level logger data.

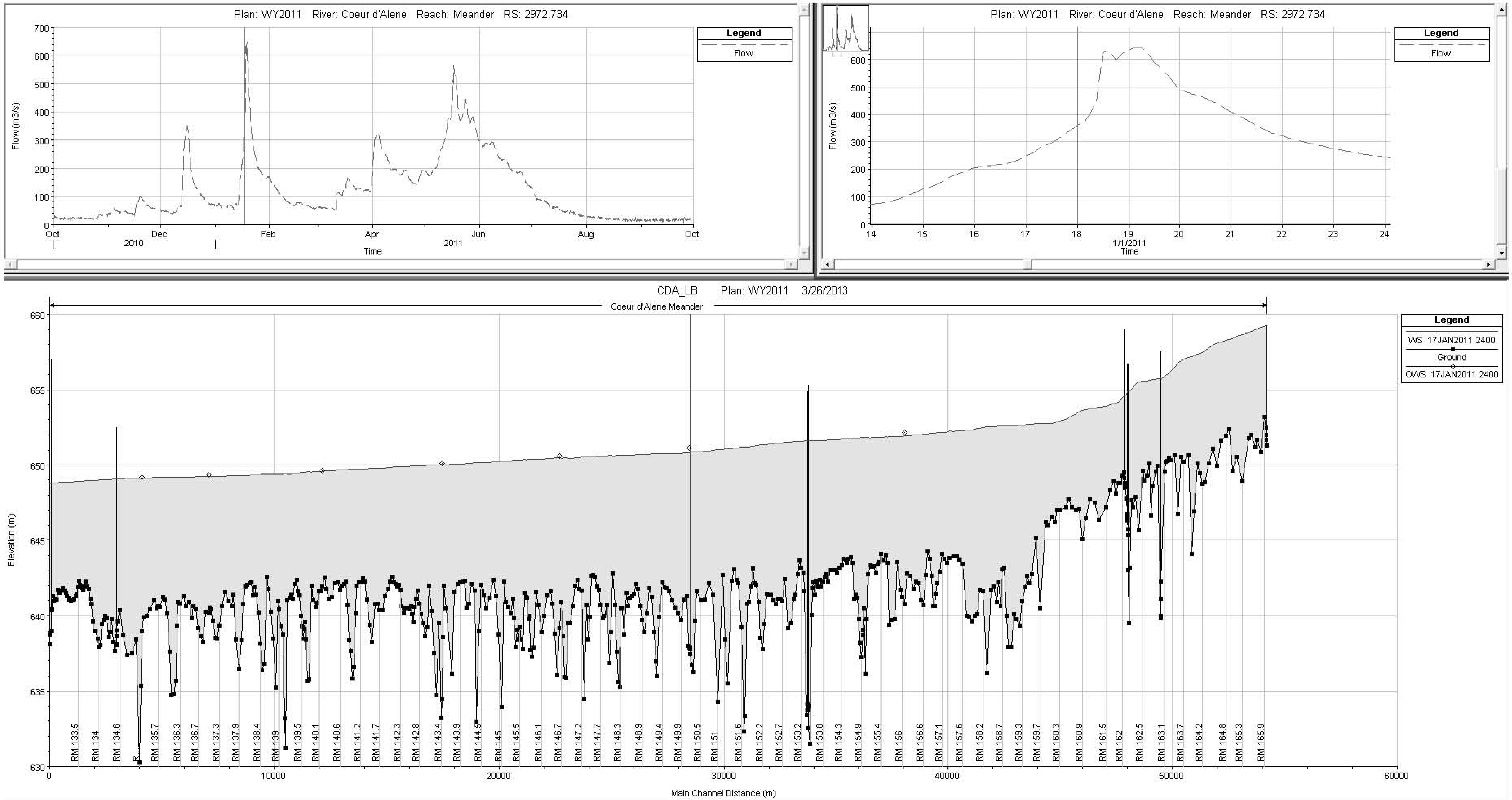


Exhibit 32.d.i. Modeled water surface elevation profile of the rising limb of the January 2011 event, including comparison with level logger data.

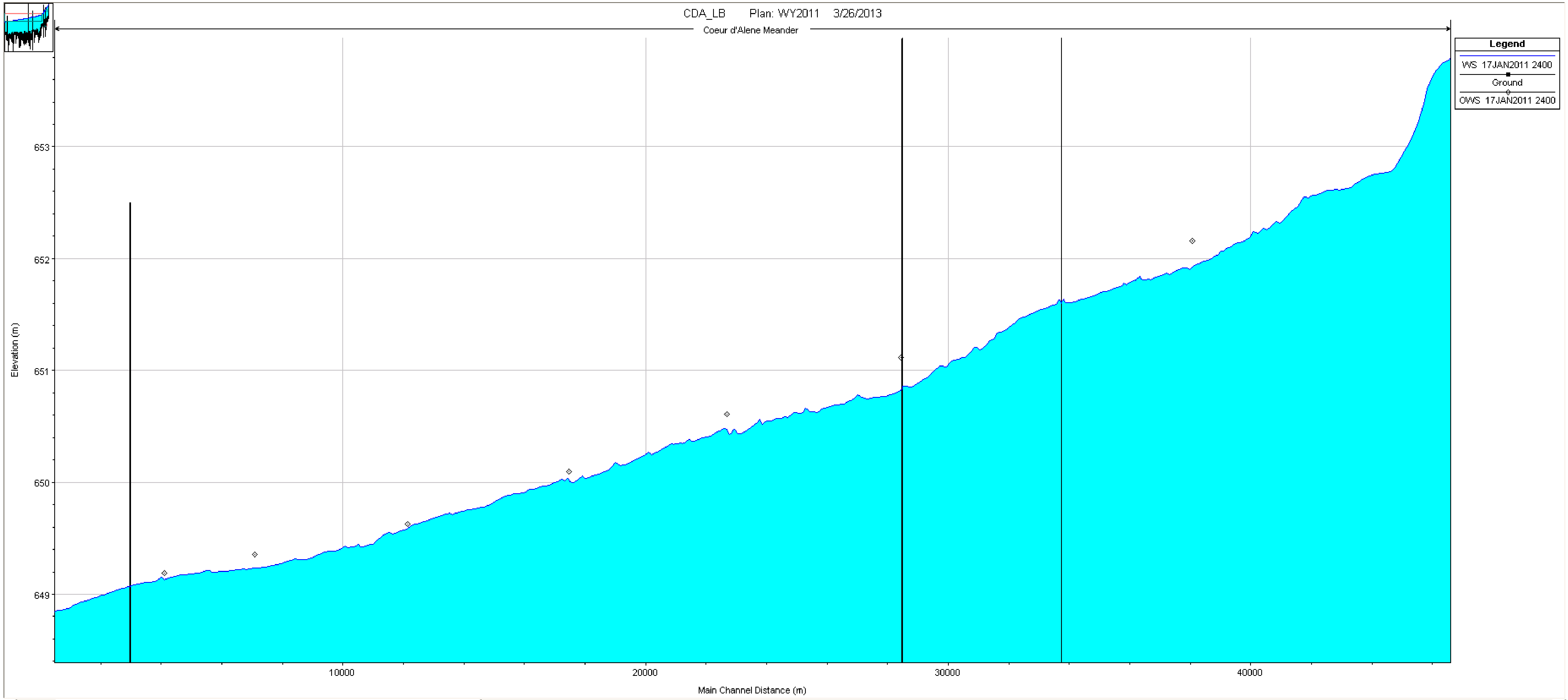


Exhibit 32.d.ii. Close-up of the modeled water surface elevation profile of the rising limb of the January 2011 event, including comparison with level logger data.

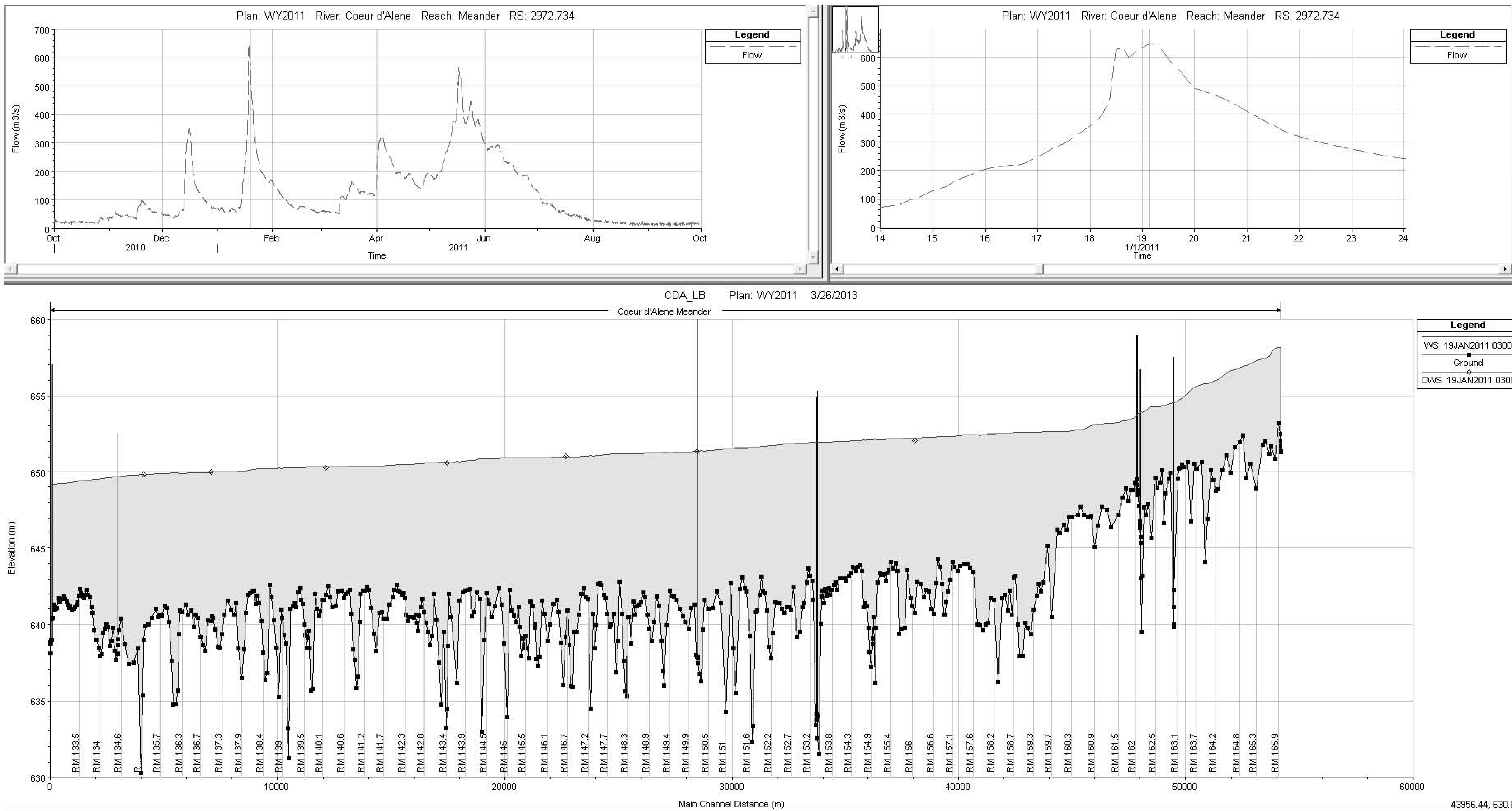


Exhibit 32.e.i. Modeled water surface elevation profile of the peak of the January 2011 event, including comparison with level logger data.

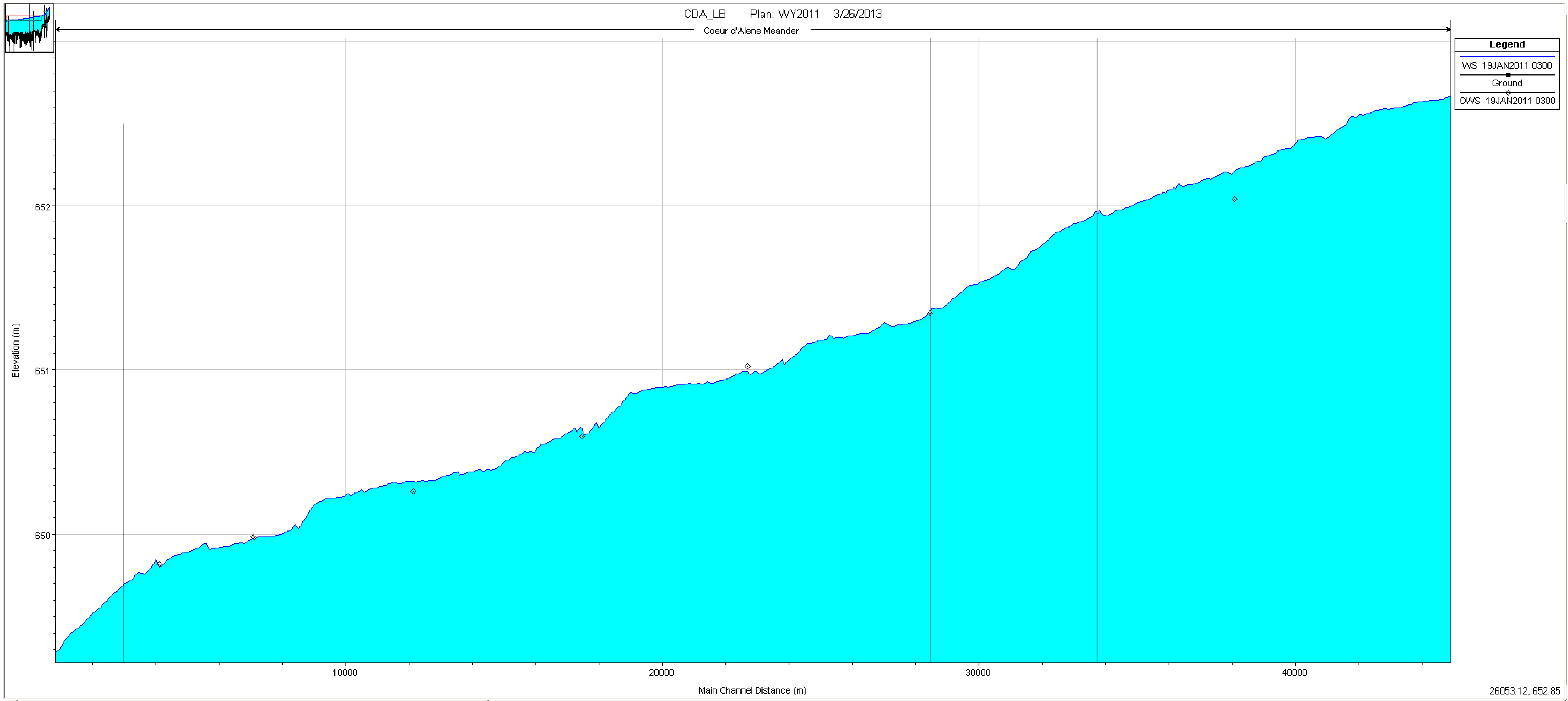


Exhibit 32.e.i. Close-up of the modeled water surface elevation profile of the peak of the January 2011 event, including comparison with level logger data.

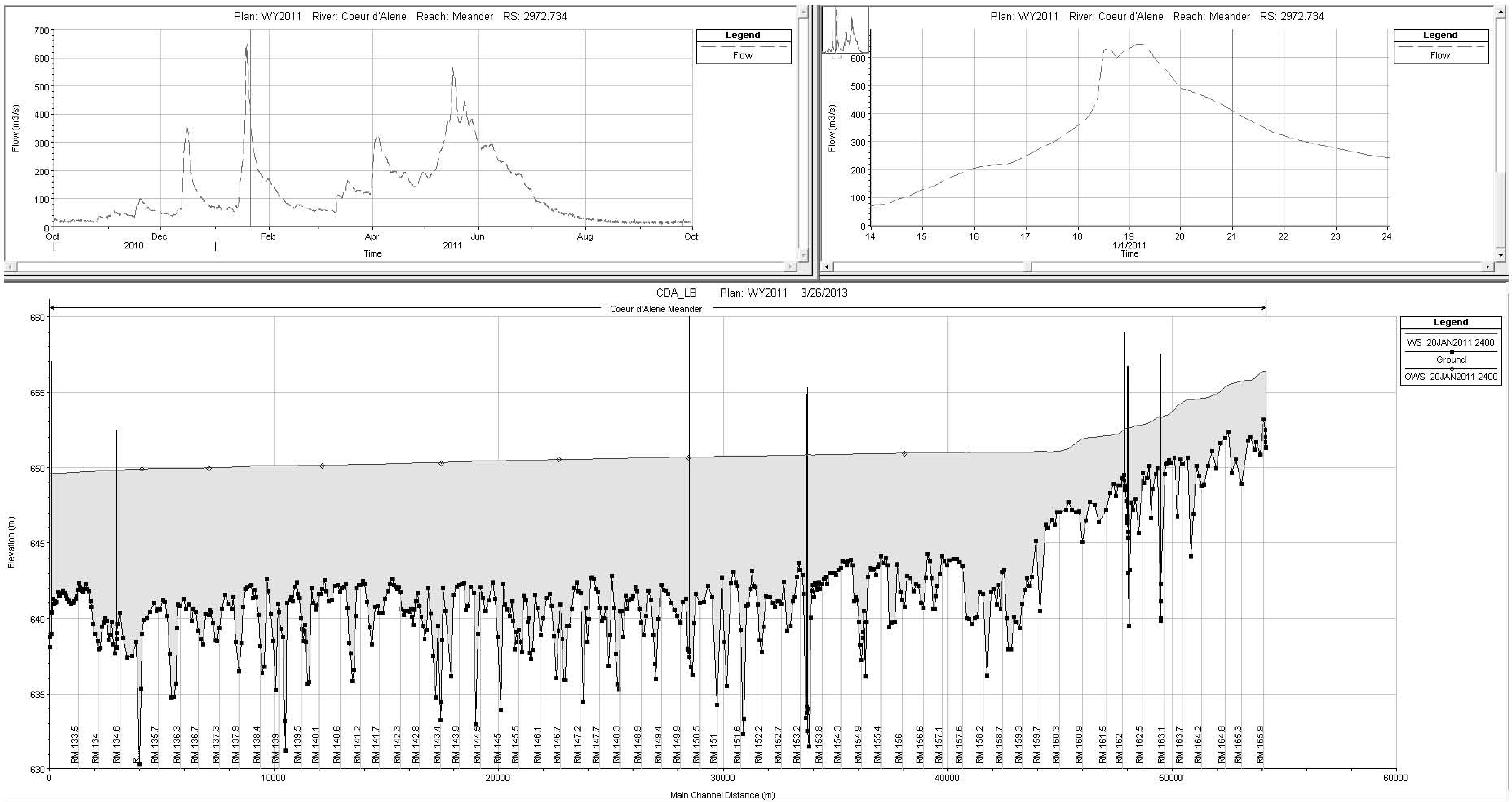


Exhibit 32.f.i. Modeled water surface elevation profile of the falling limb of the January 2011 event, including comparison with level logger data.

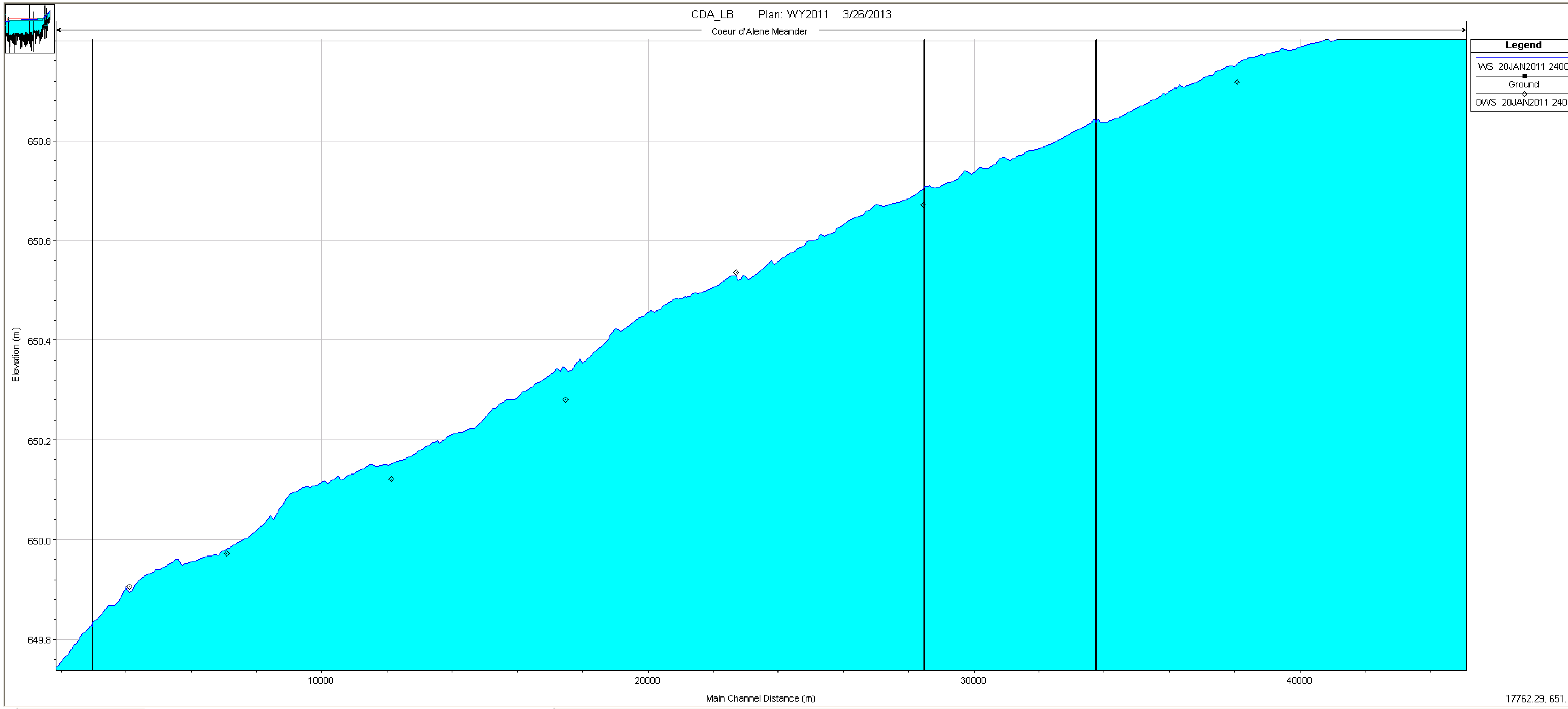


Exhibit 32.f.ii. Close-up of the modeled water surface elevation profile of the falling limb of the January 2011 event, including comparison with level logger data.

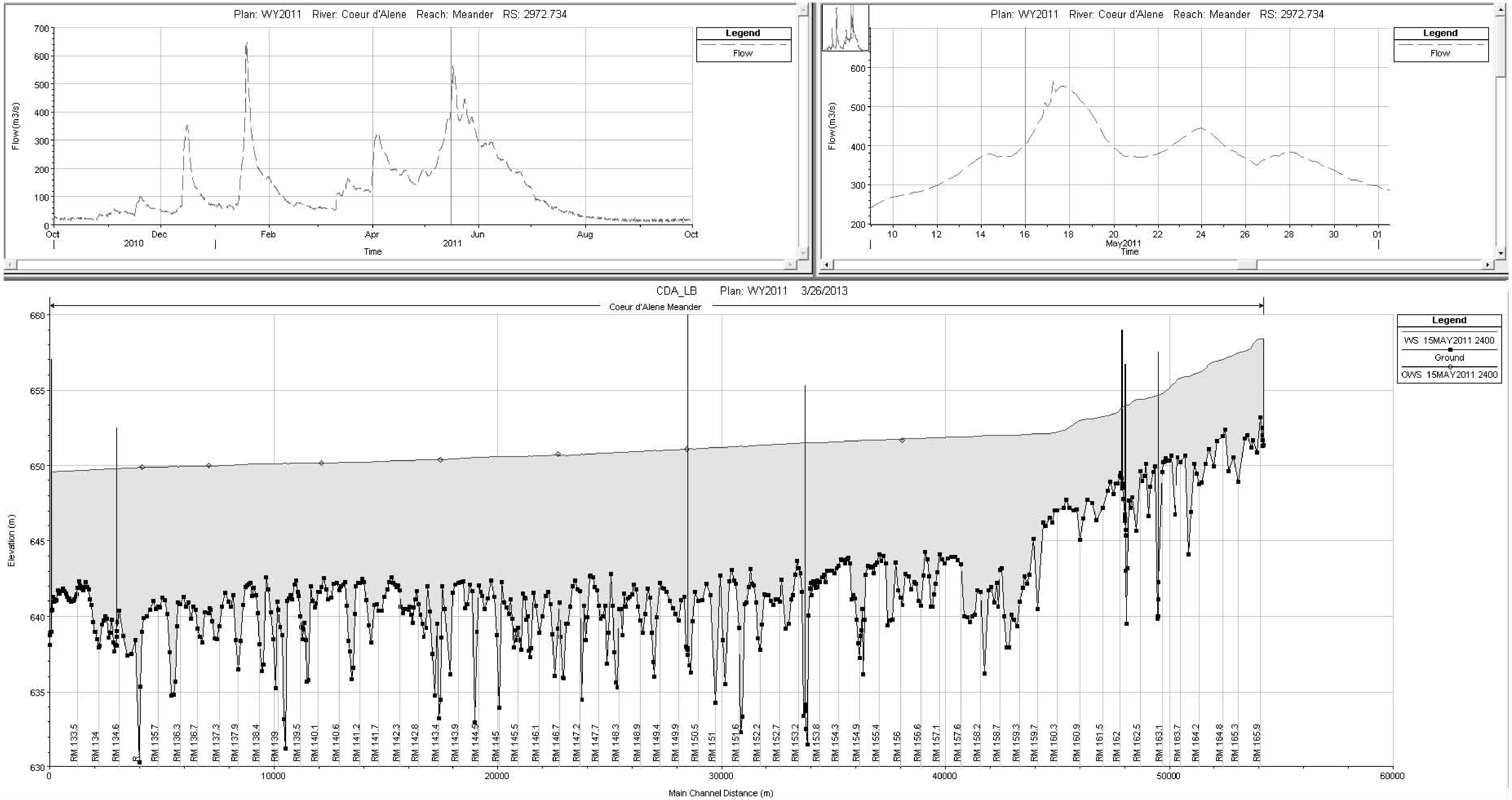


Exhibit 32.g.i. Modeled water surface elevation profile of the rising limb of the May 2011 event, including comparison with level logger data.

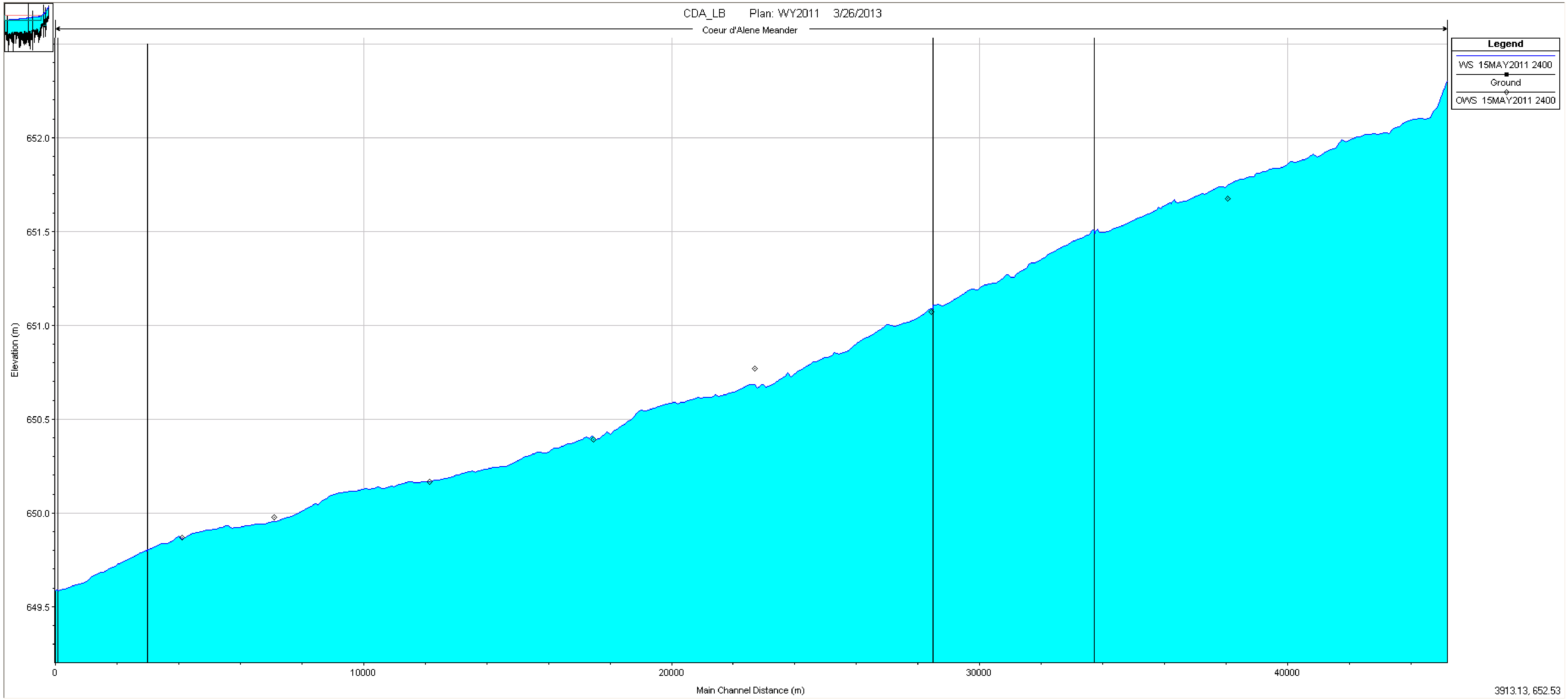


Exhibit 32.g.i. Close-up of the modeled water surface elevation profile of the rising limb of the May 2011 event, including comparison with level logger data.

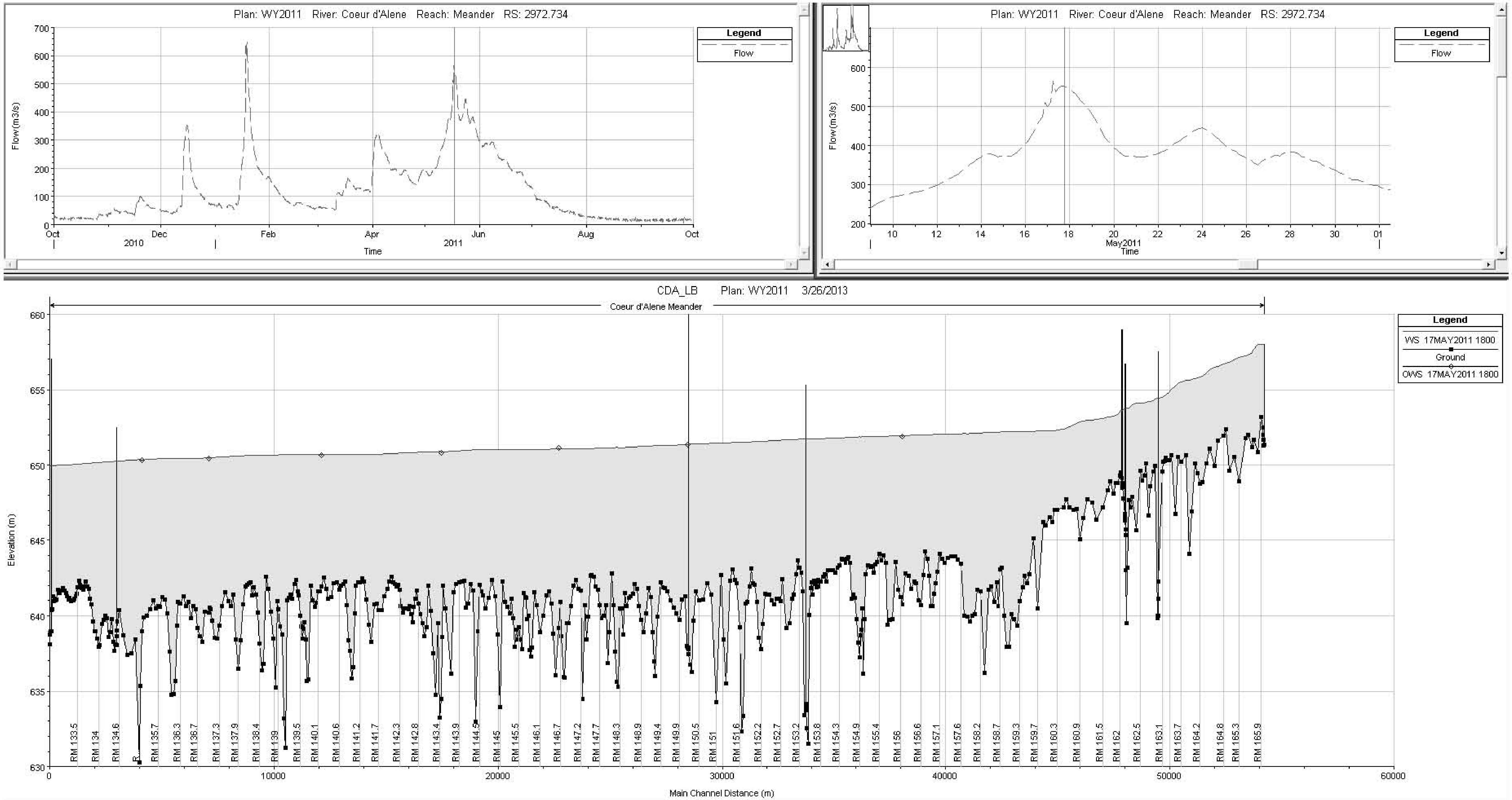


Exhibit 32.h.i. Modeled water surface elevation profile of the peak of the May 2011 event, including comparison with level logger data.

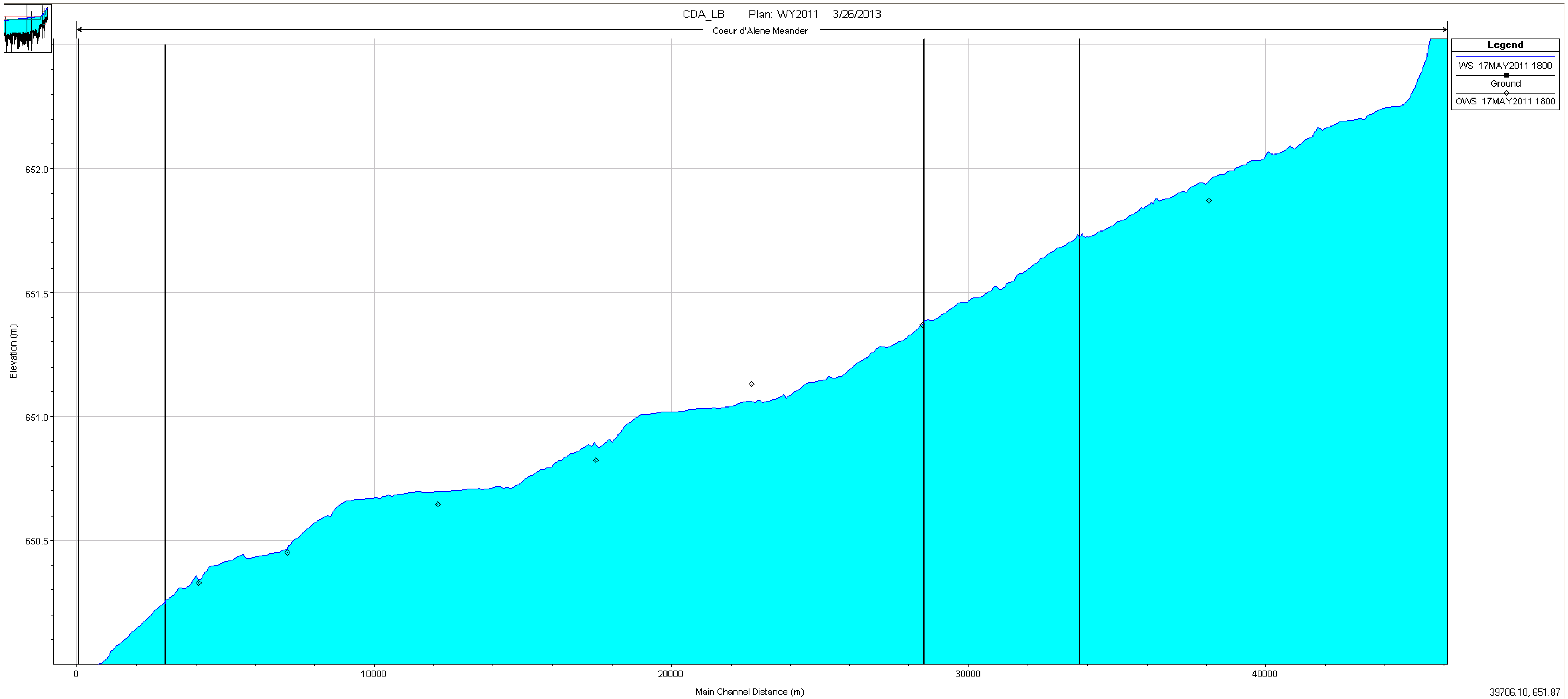


Exhibit 32.h.ii. Close-up of the modeled water surface elevation profile of the peak of the May 2011 event, including comparison with level logger data.

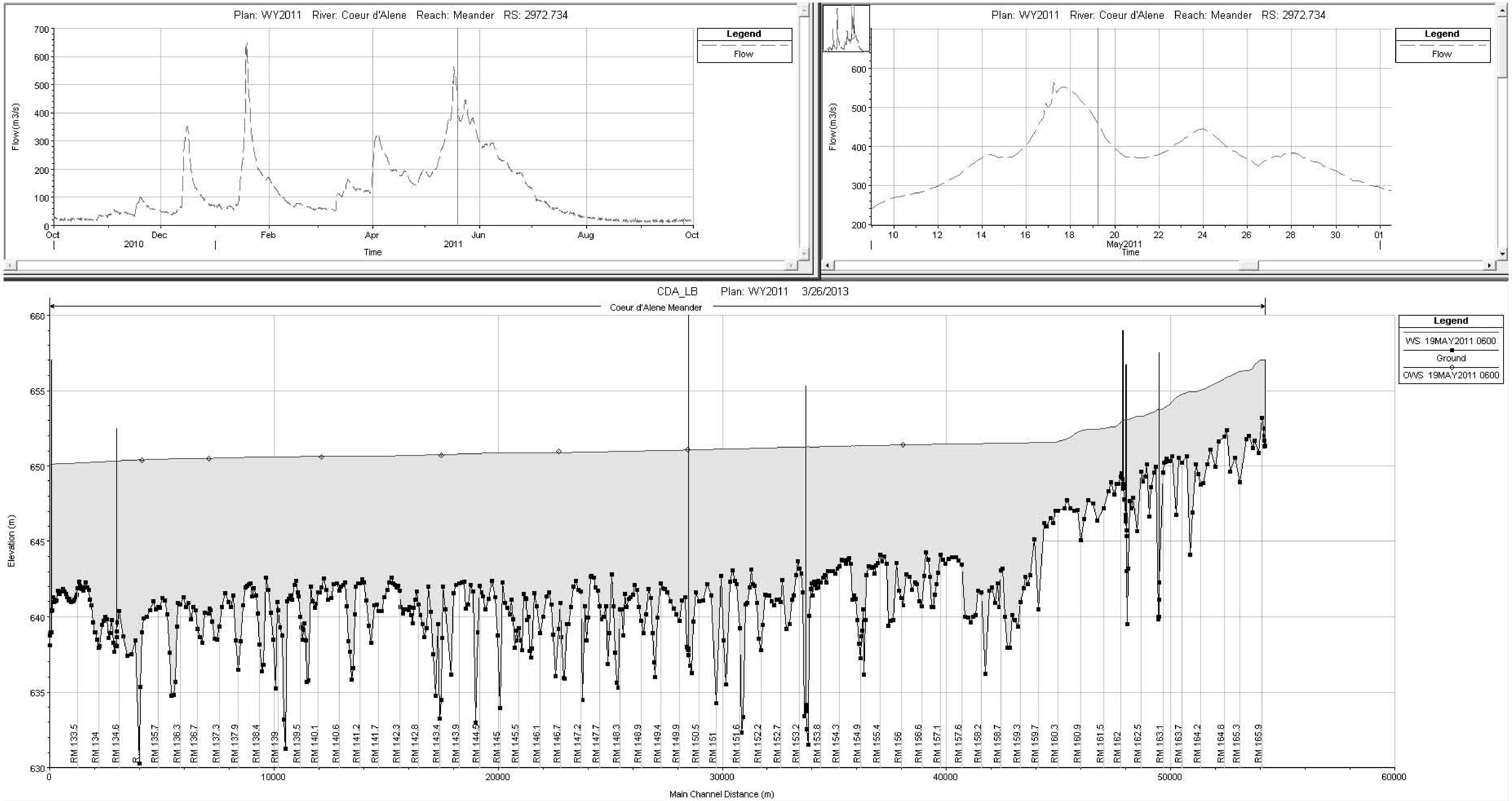


Exhibit 32.i.i. Modeled water surface elevation profile of the falling limb of the May 2011 event, including comparison with level logger data.

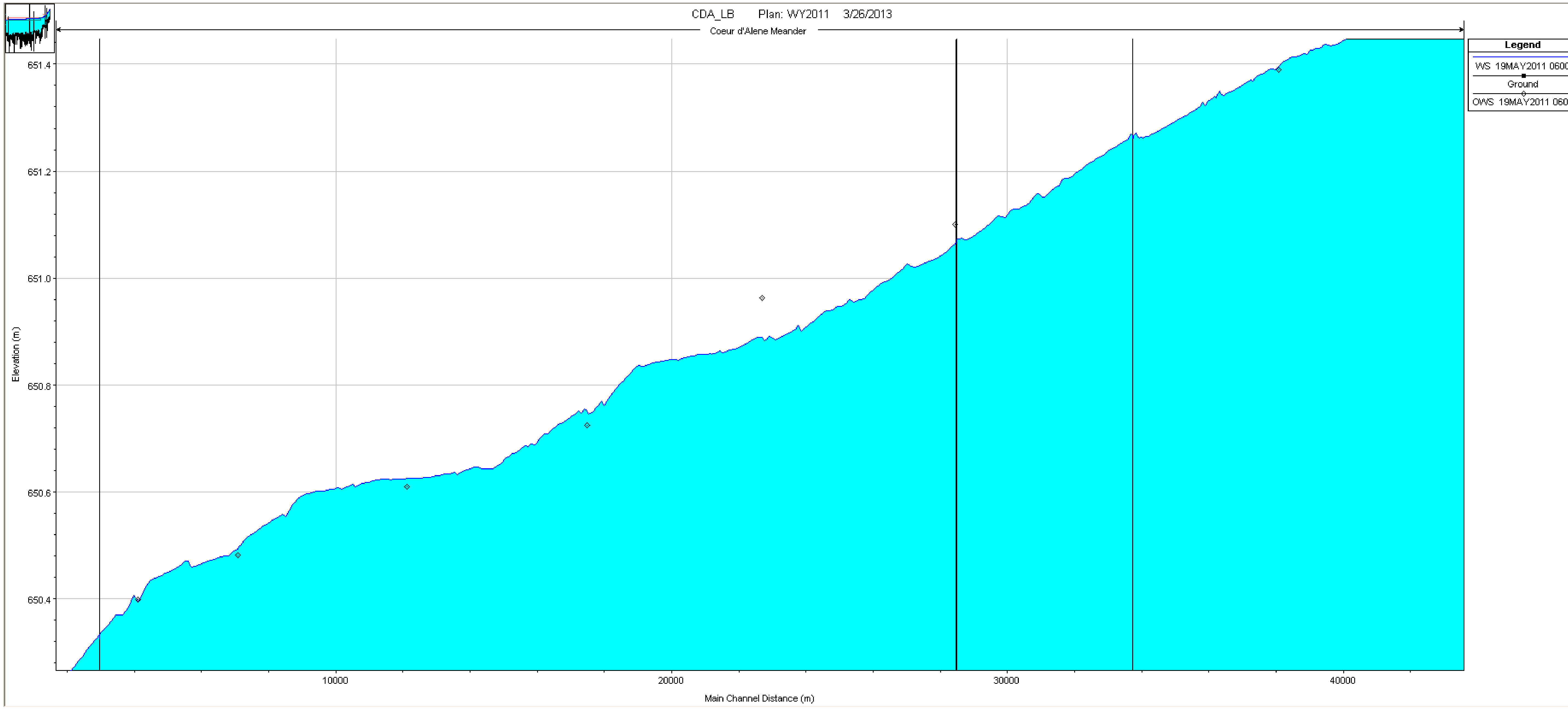
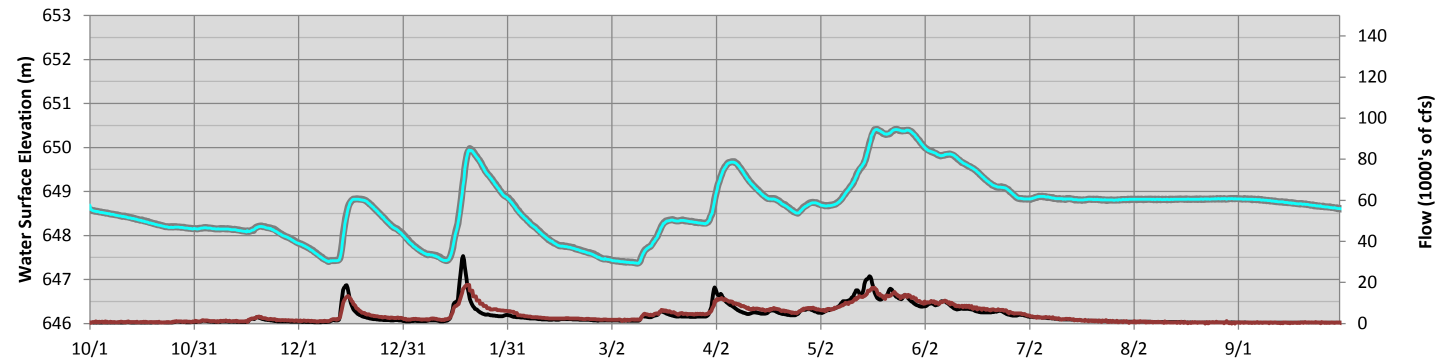
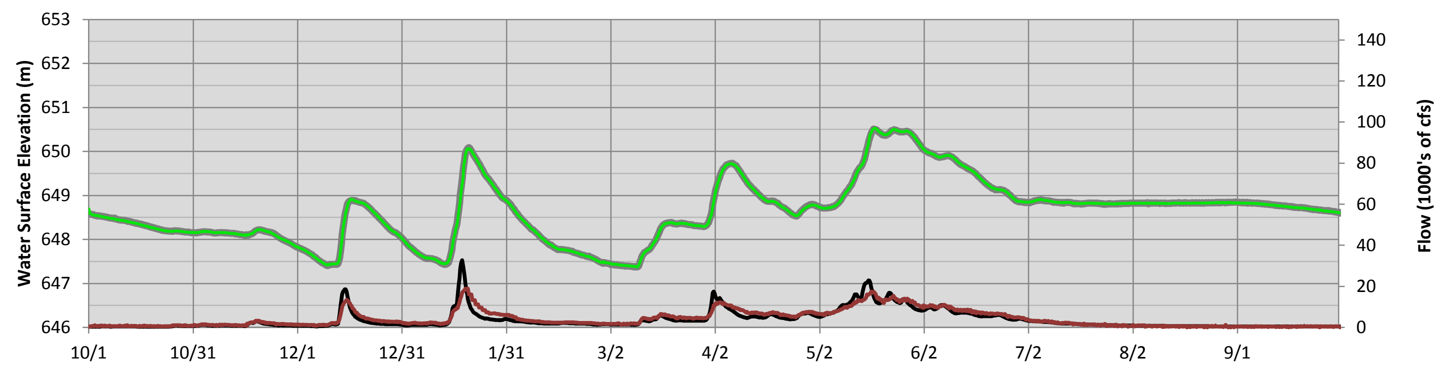


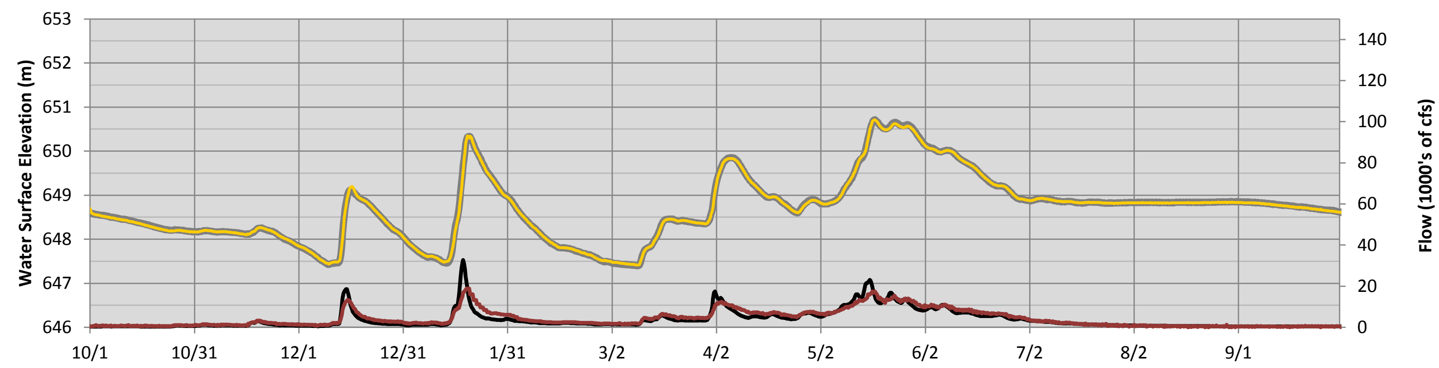
Exhibit 32.i.ii. Close-up of the modeled water surface elevation profile of the falling limb of the May 2011 event, including comparison with level logger data.



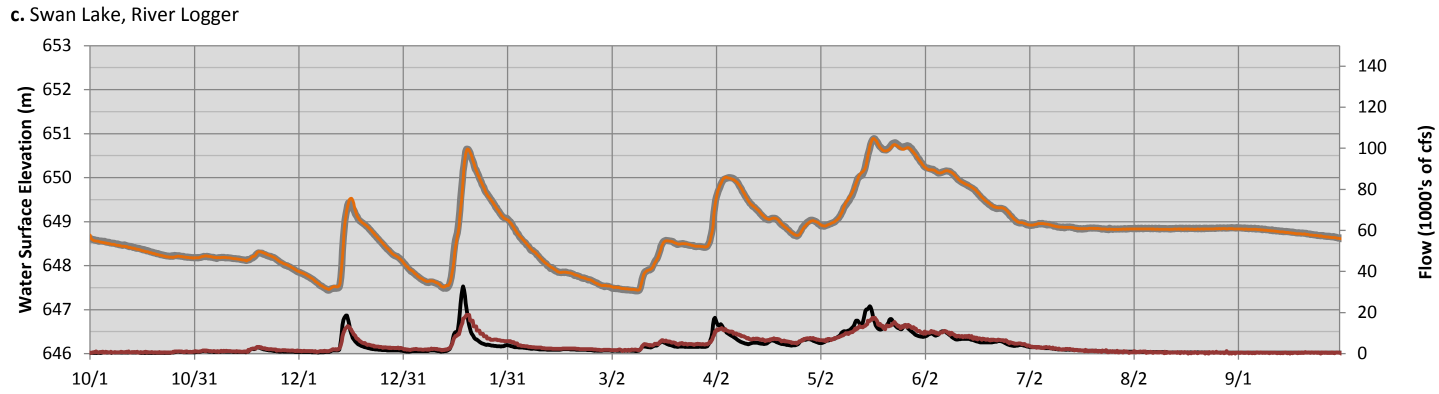
a. Thompson Lake, River Logger



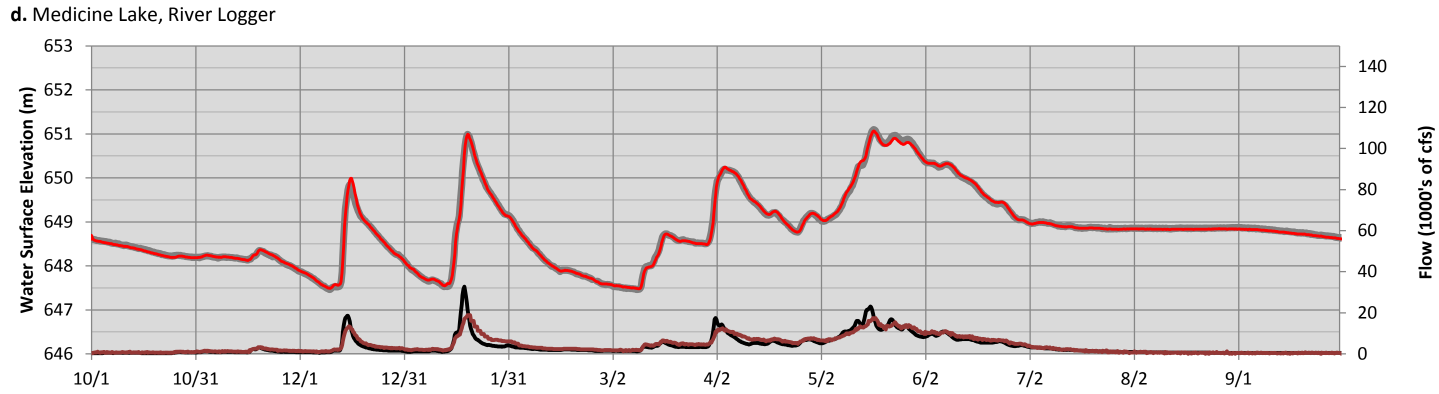
b. Blue Lake, River Logger



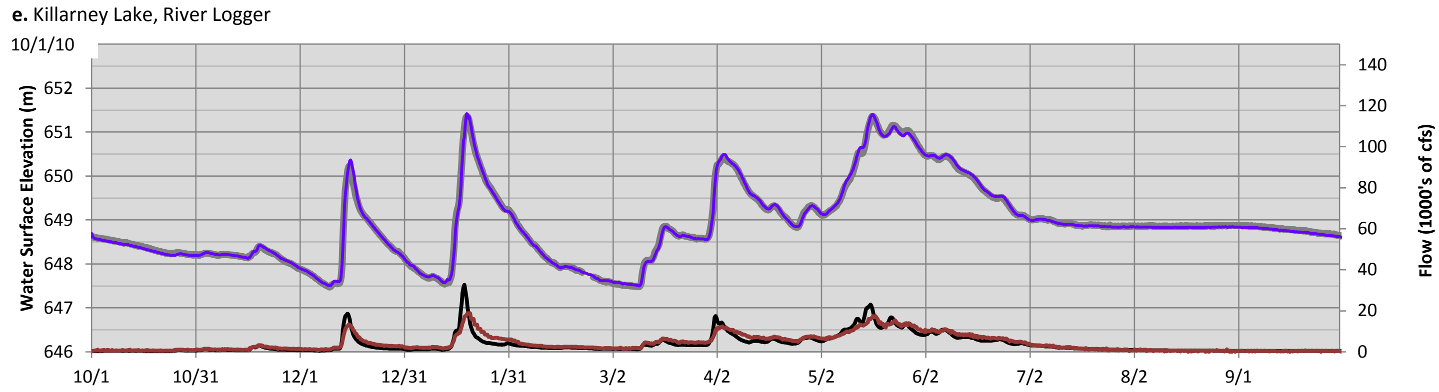
c. Swan Lake, River Logger



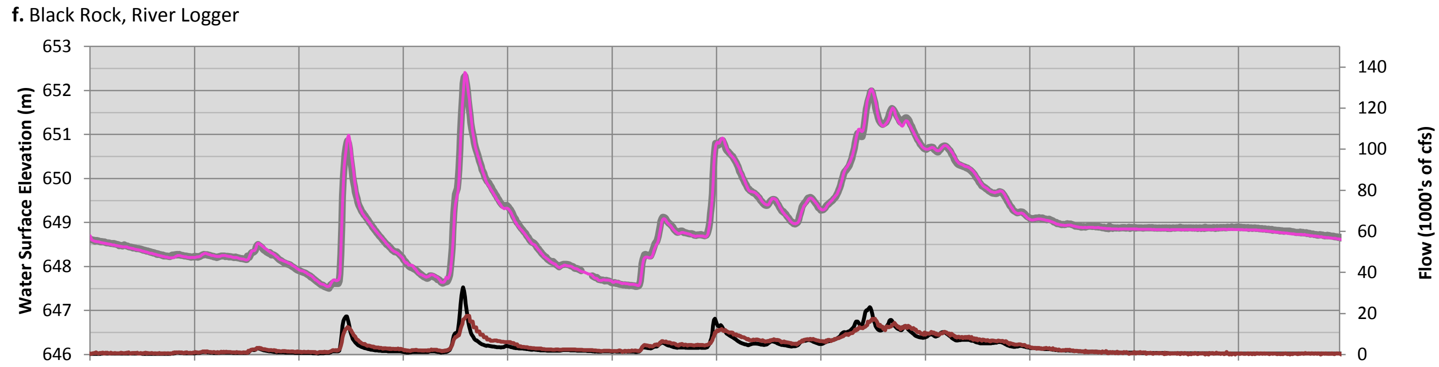
d. Medicine Lake, River Logger



e. Killarney Lake, River Logger



f. Black Rock, River Logger

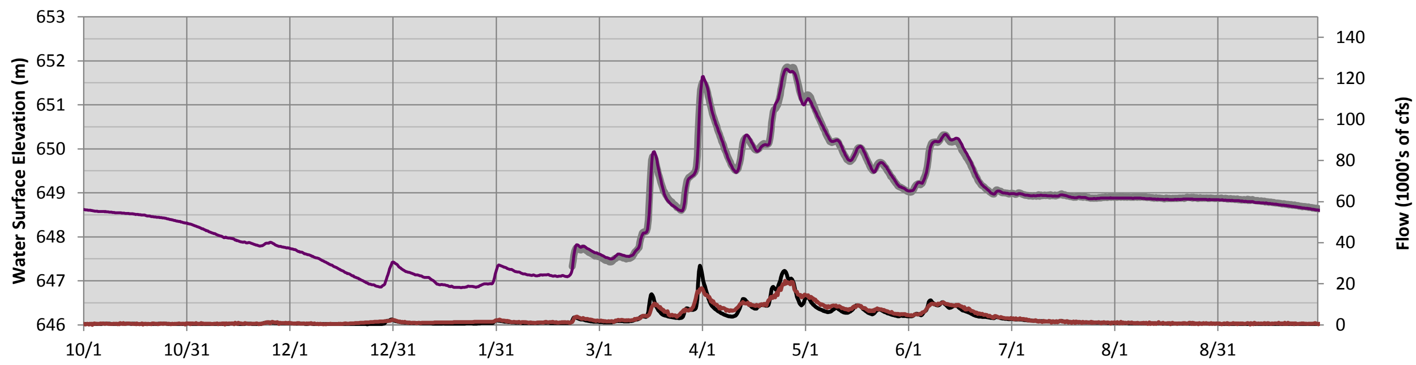


g. Dudley, River Logger

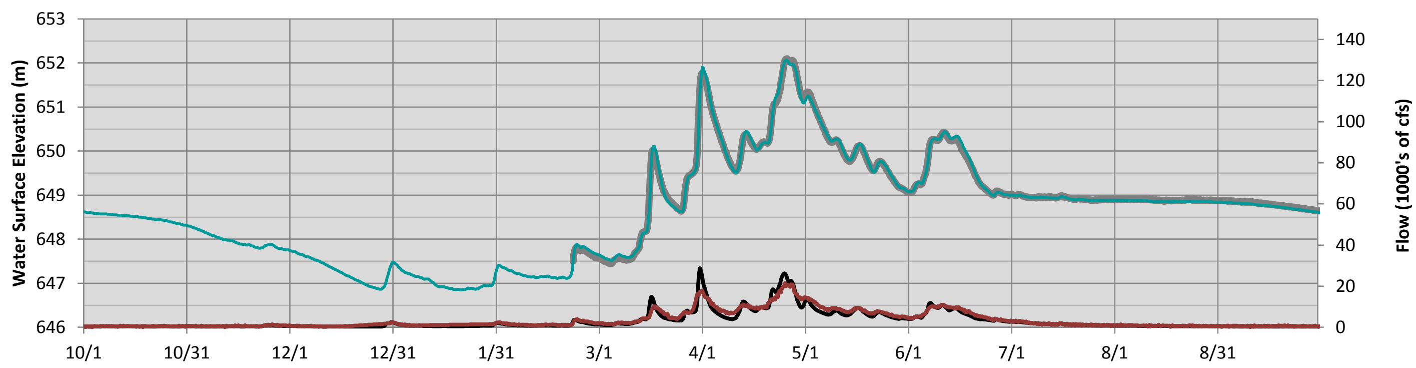
Legend

Cataldo Flow	Thompson Lake	Blue Lake	Swan Lake
Medicine Lake	Harrison Flow	Killarney Lake	Black Rock
Dudley	Level Logger		

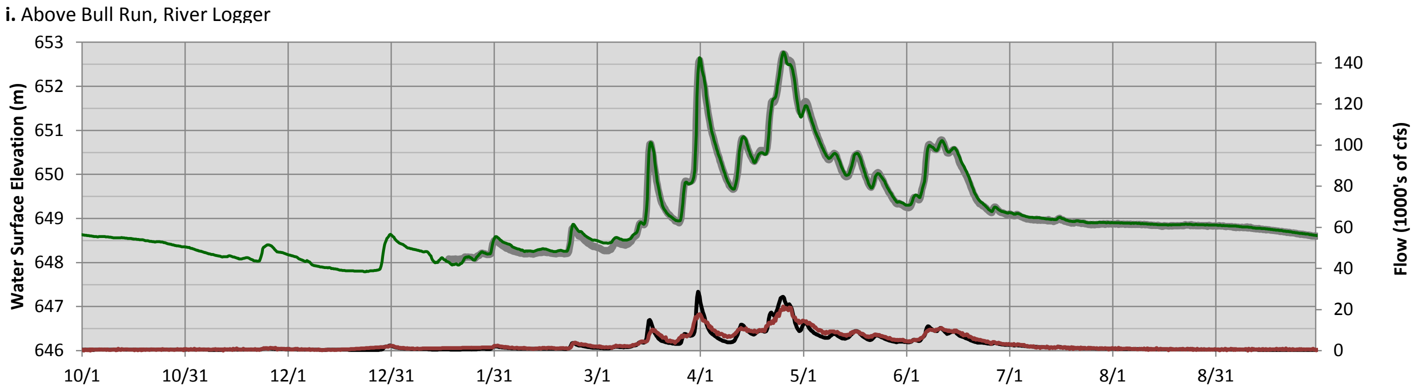
Exhibit 30-*c1*
Individual River Gage Calibration - WY 2011
Water Surface Elevation Time Series
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



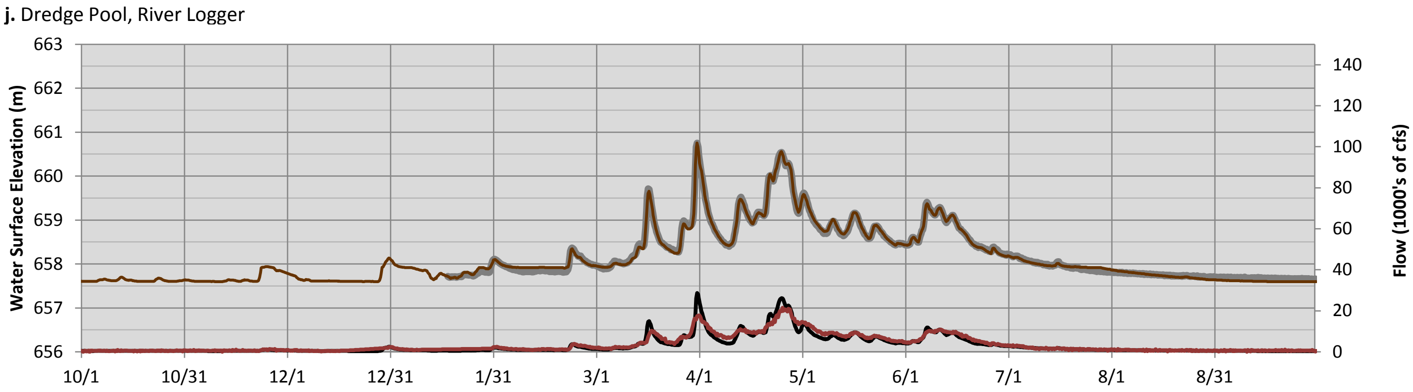
h. Below Bull Run, River Logger



i. Above Bull Run, River Logger



j. Dredge Pool, River Logger

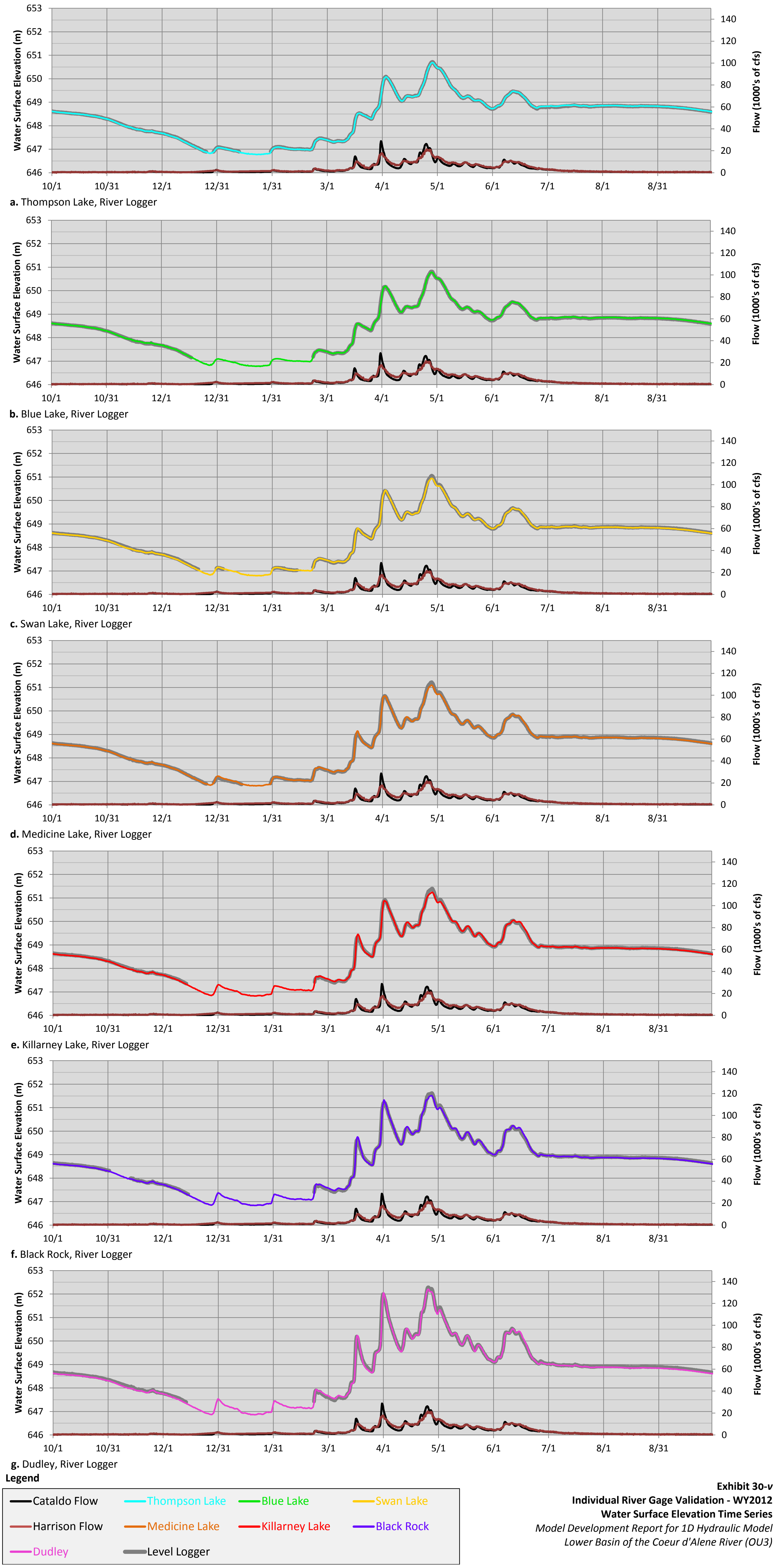


k. Confluence, River Logger

Legend

Cataldo Flow | Harrison Flow | Level Logger | Below Bull Run
Above Bull Run | Dredge Pool | Confluence

Exhibit 30-*c2*
Individual River Gage Calibration - WY 2012
Water Surface Elevation Time Series
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



a. Thompson Lake, River Logger

b. Blue Lake, River Logger

c. Swan Lake, River Logger

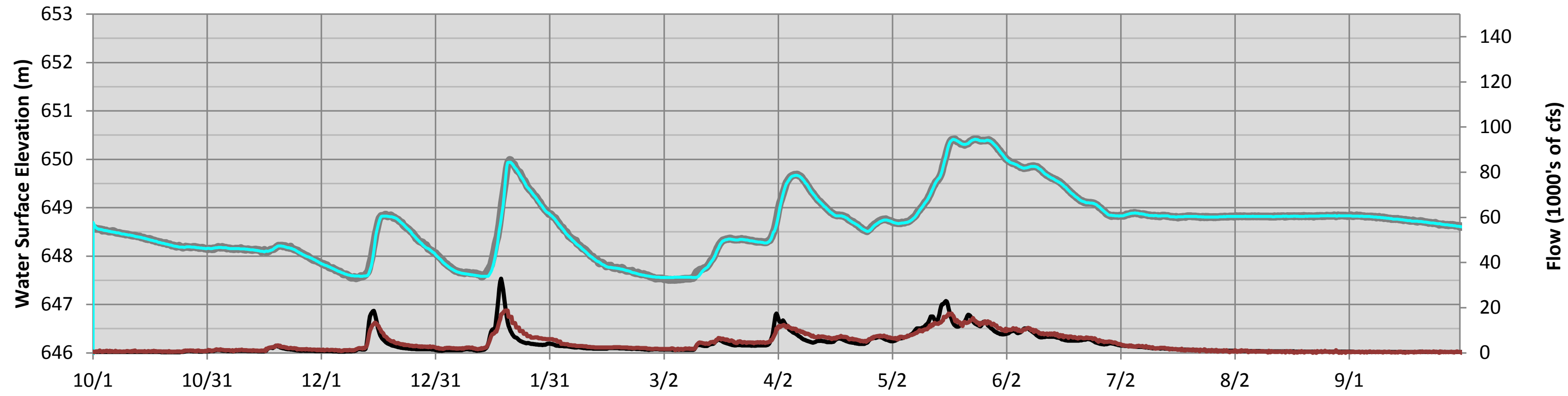
d. Medicine Lake, River Logger

e. Killarney Lake, River Logger

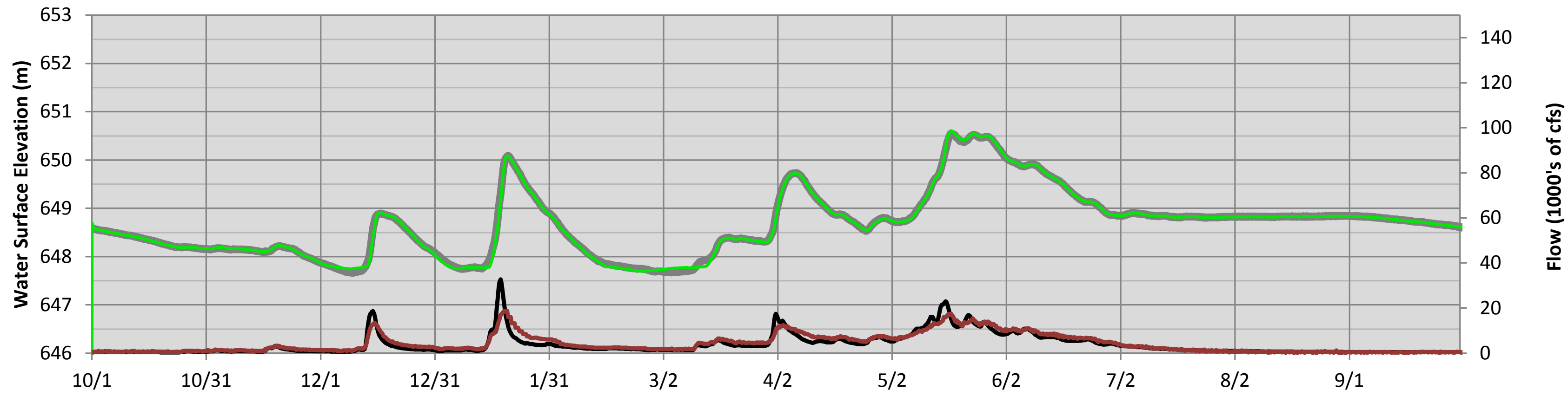
f. Black Rock, River Logger

g. Dudley, River Logger

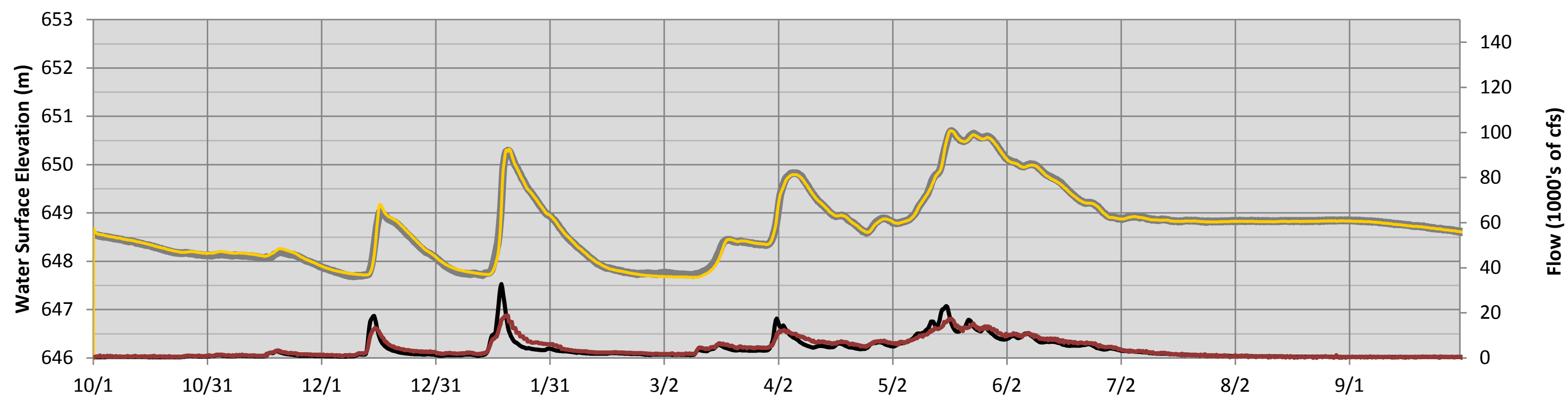
Exhibit 30-*v*
Individual River Gage Validation - WY2012
Water Surface Elevation Time Series
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



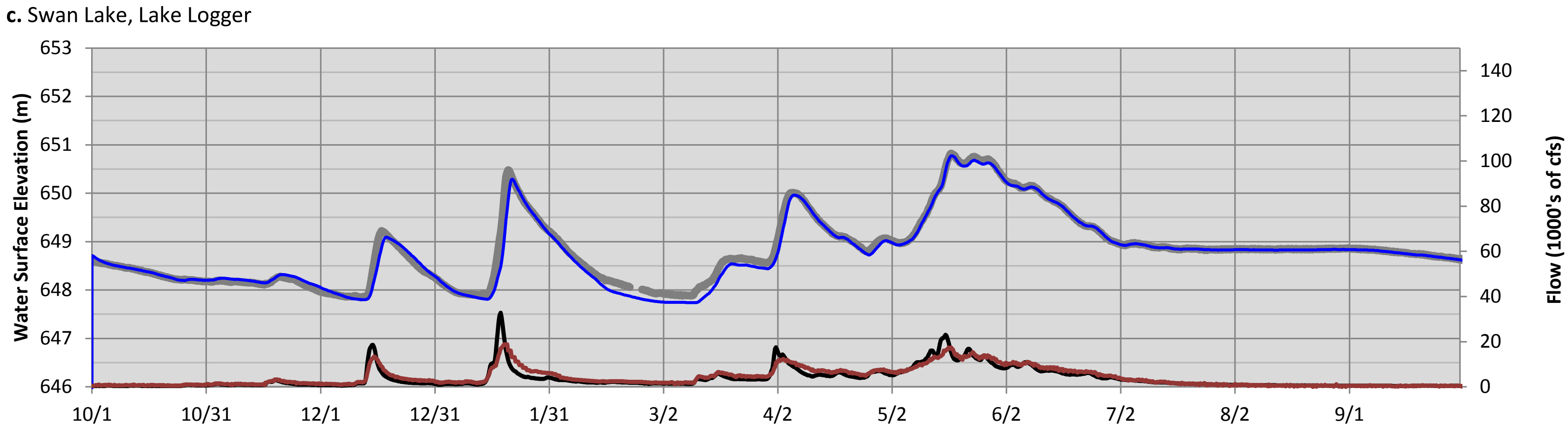
a. Thompson Lake, Lake Logger



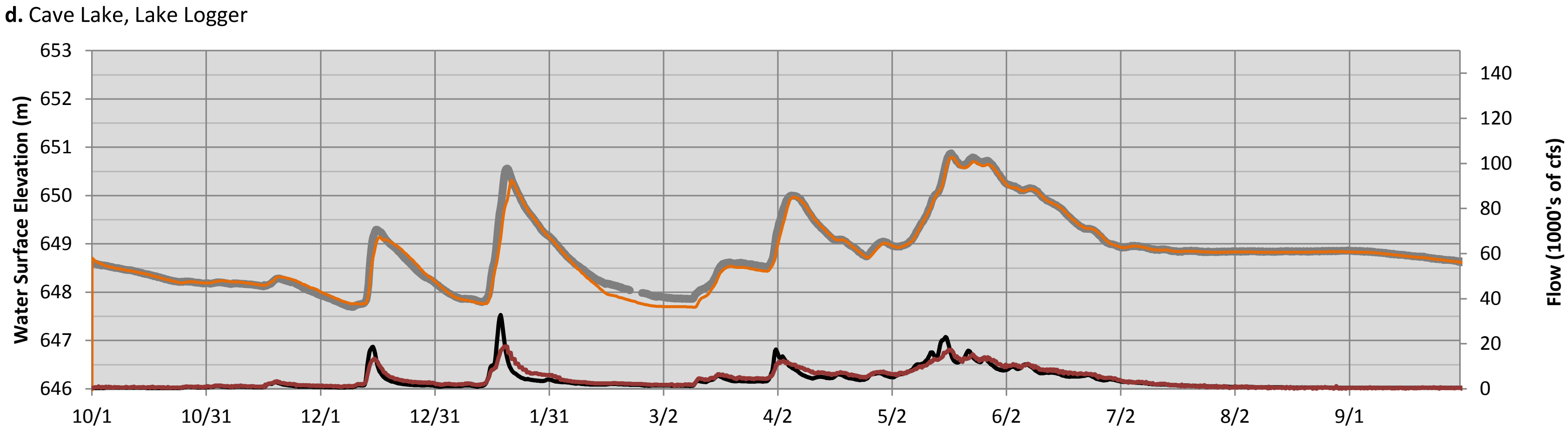
b. Blue Lake, Lake Logger



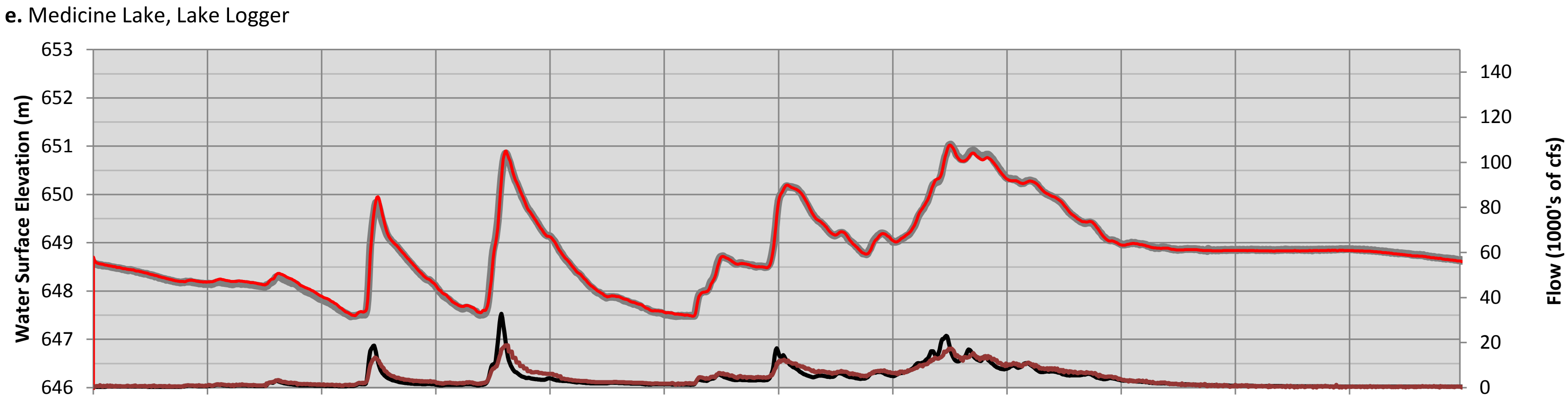
c. Swan Lake, Lake Logger



d. Cave Lake, Lake Logger



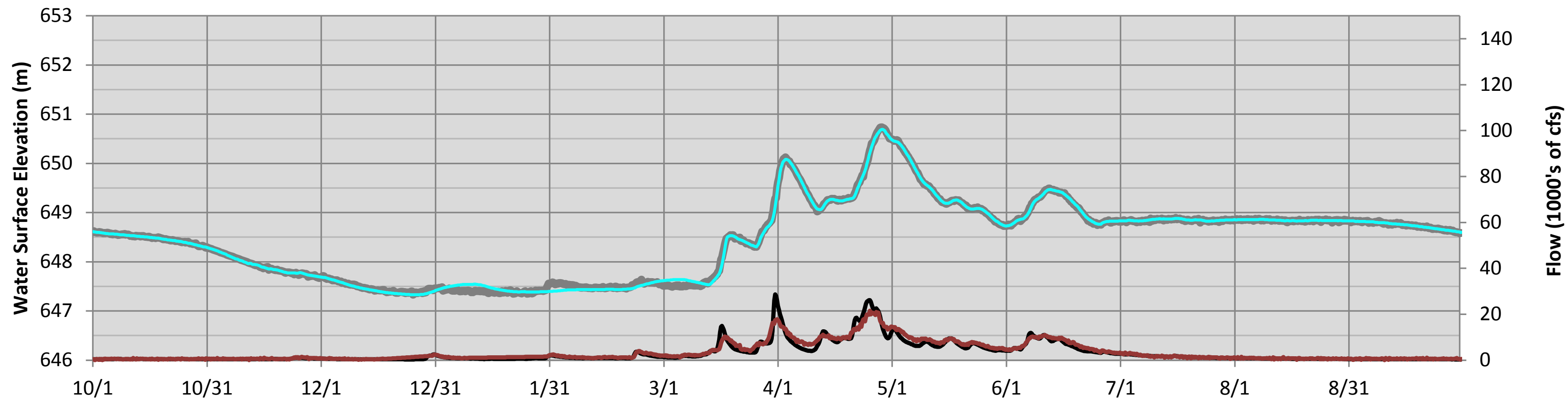
e. Medicine Lake, Lake Logger



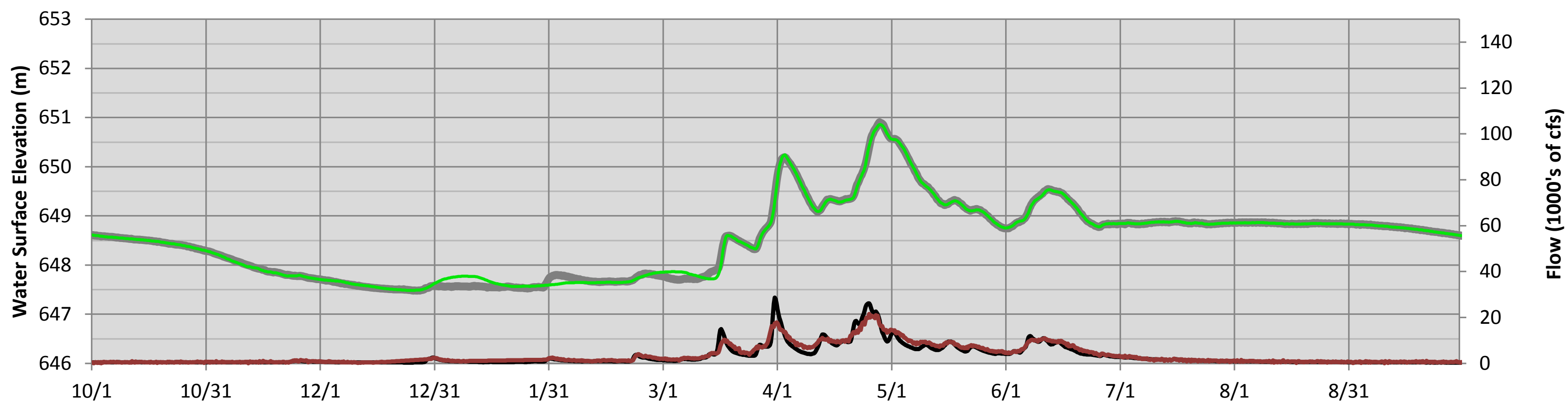
e. Killarney Lake, Lake Logger

Legend

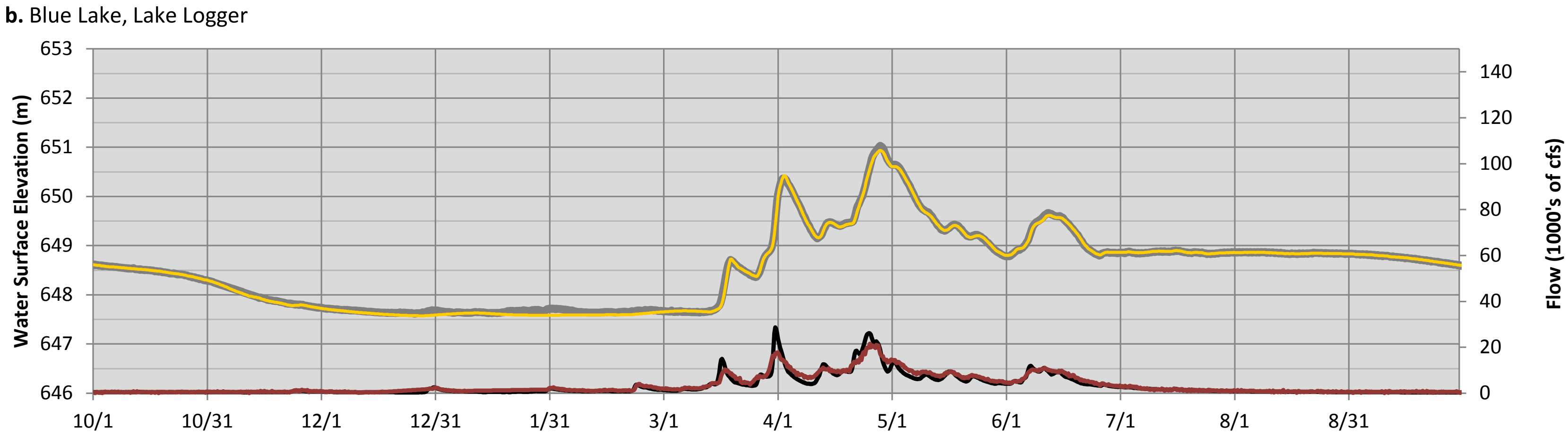
Exhibit 3n-*c*
Individual Lake Gage Calibration - WY 2011
Water Surface Elevation Time Series
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



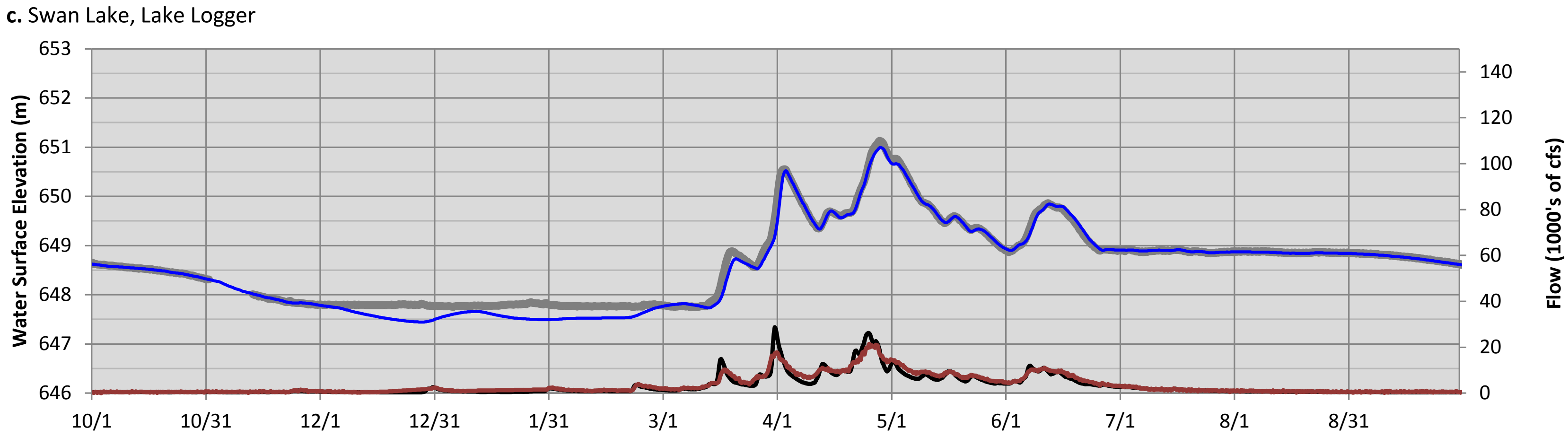
a. Thompson Lake, Lake Logger



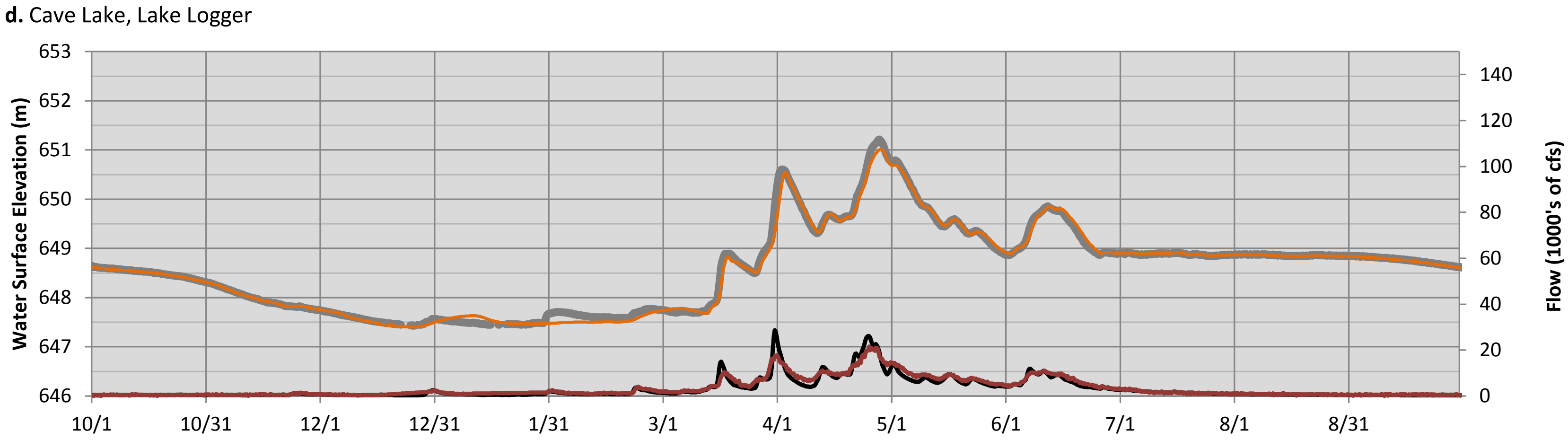
b. Blue Lake, Lake Logger



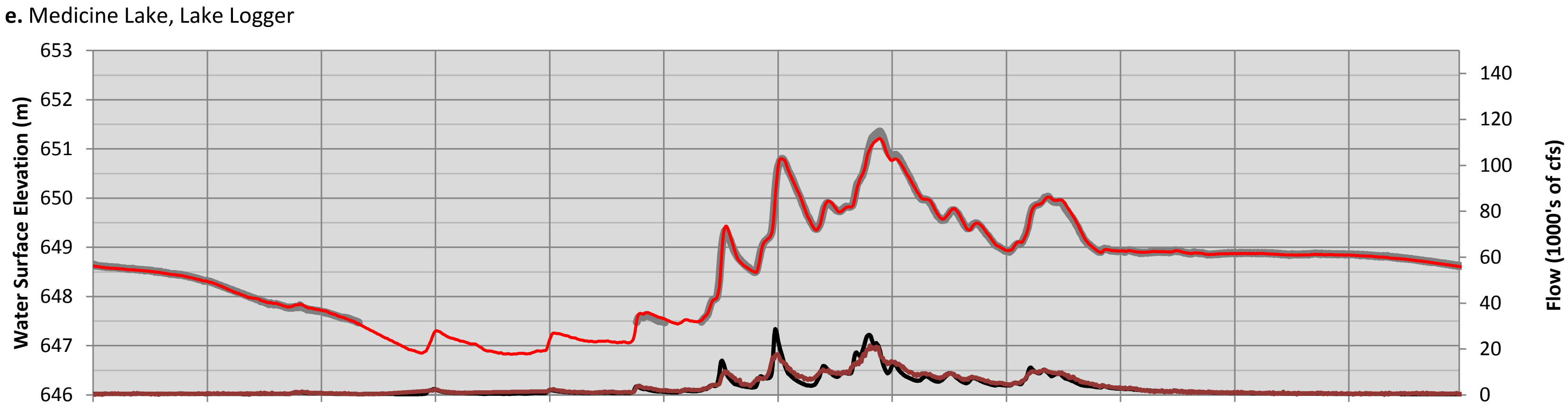
c. Swan Lake, Lake Logger



d. Cave Lake, Lake Logger



e. Medicine Lake, Lake Logger

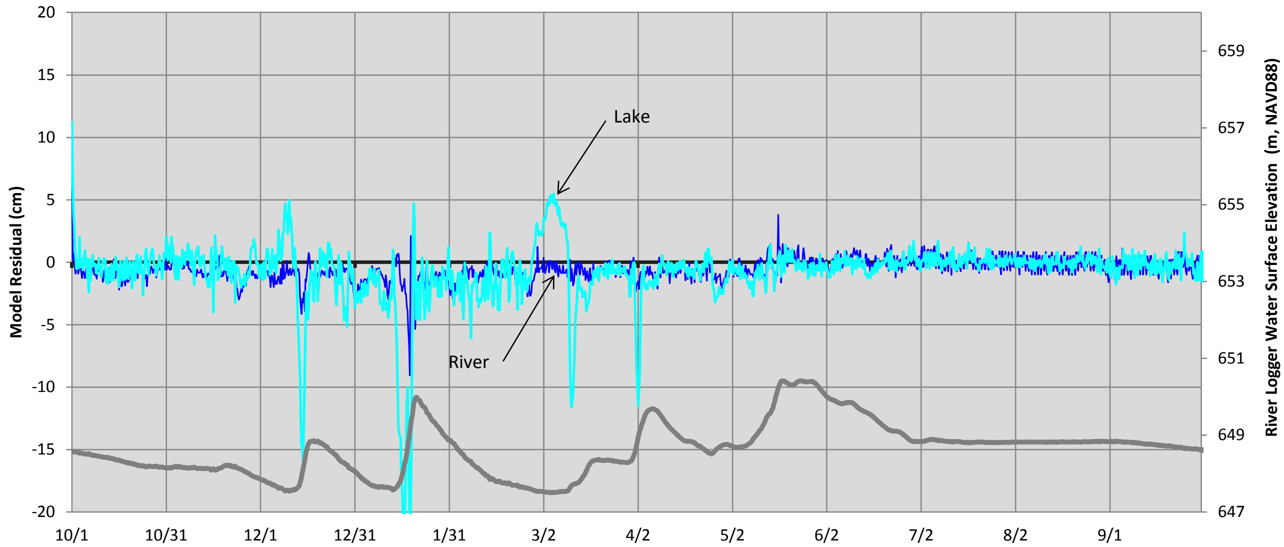


e. Killarney Lake, Lake Logger

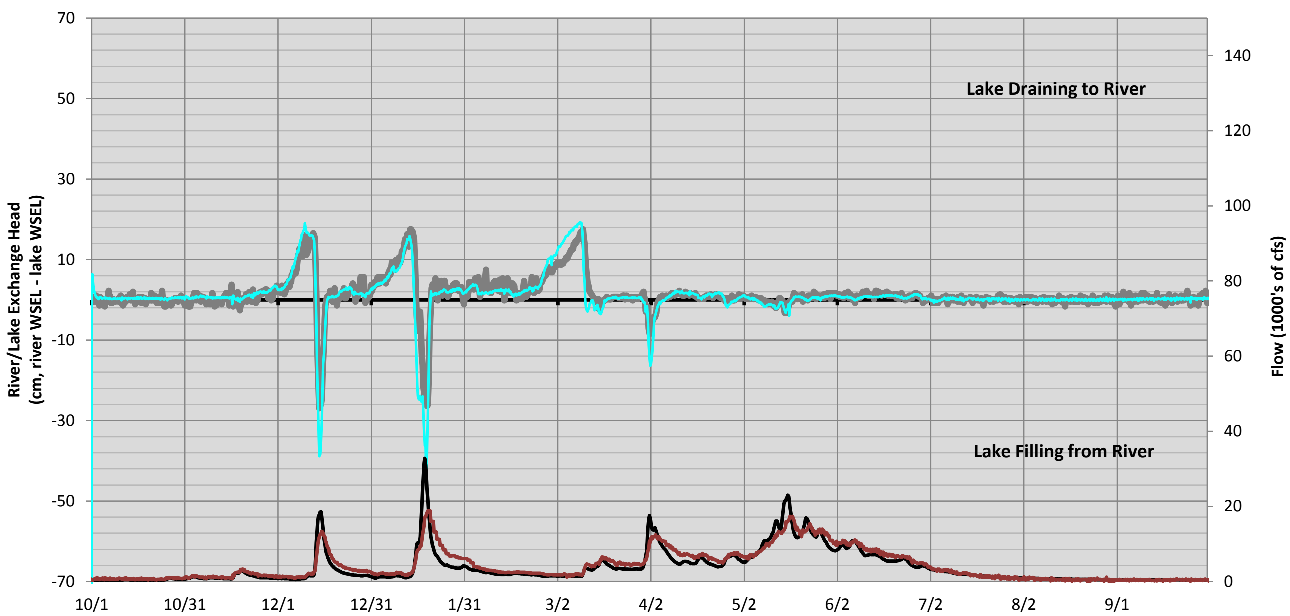
Legend

Cataldo Flow	Thompson Lake	Blue Lake
Swan Lake	Level Logger	Harrison Flow
Cave Lake	Medicine Lake	Killarney Lake

Exhibit 3n-v
Individual Lake Gage Validation - WY 2012
Water Surface Elevation Time Series
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



a. River and Lake Logger Residual

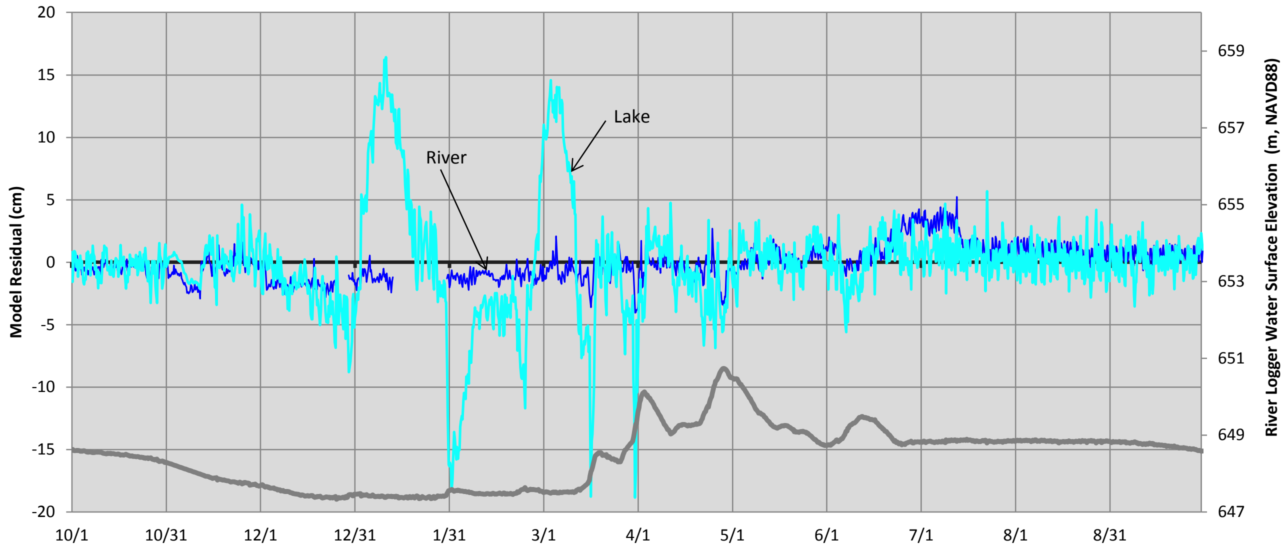


b. River/Lake Exchange

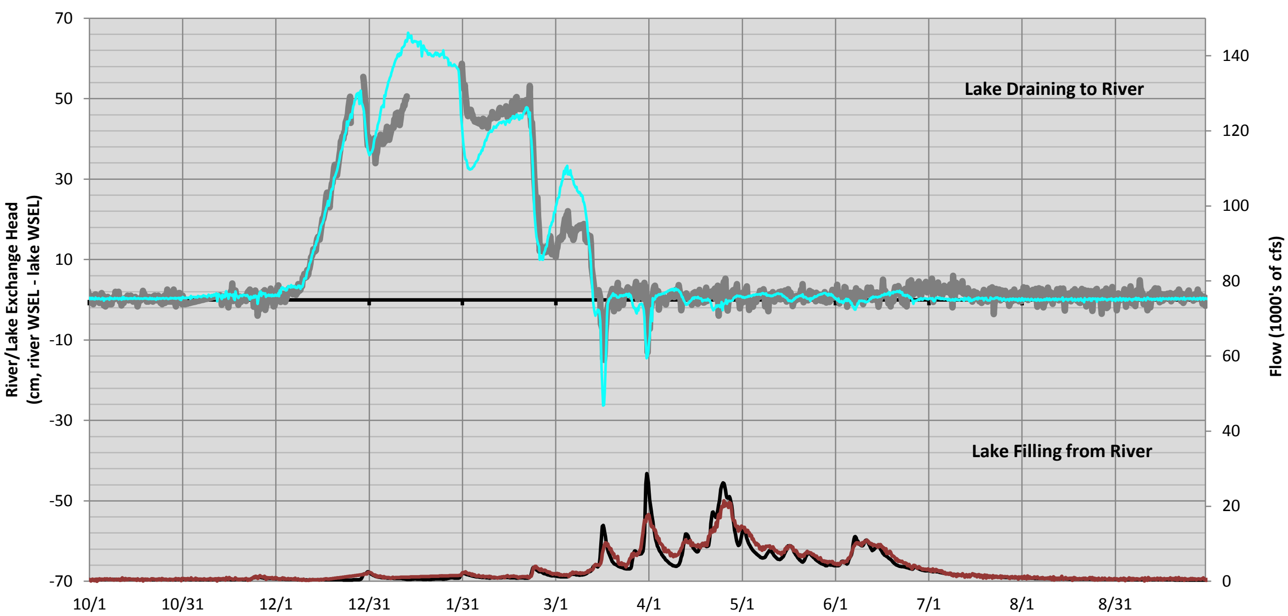
Legend

Logger	Harrison Flow
Cataldo Flow	Thompson Lake - River Logger
Thompson Lake - Lake Logger	

Exhibit 3p-*c*
Thompson Lake Residual and Exchange
WY 2011 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



a. River and Lake Logger Residual

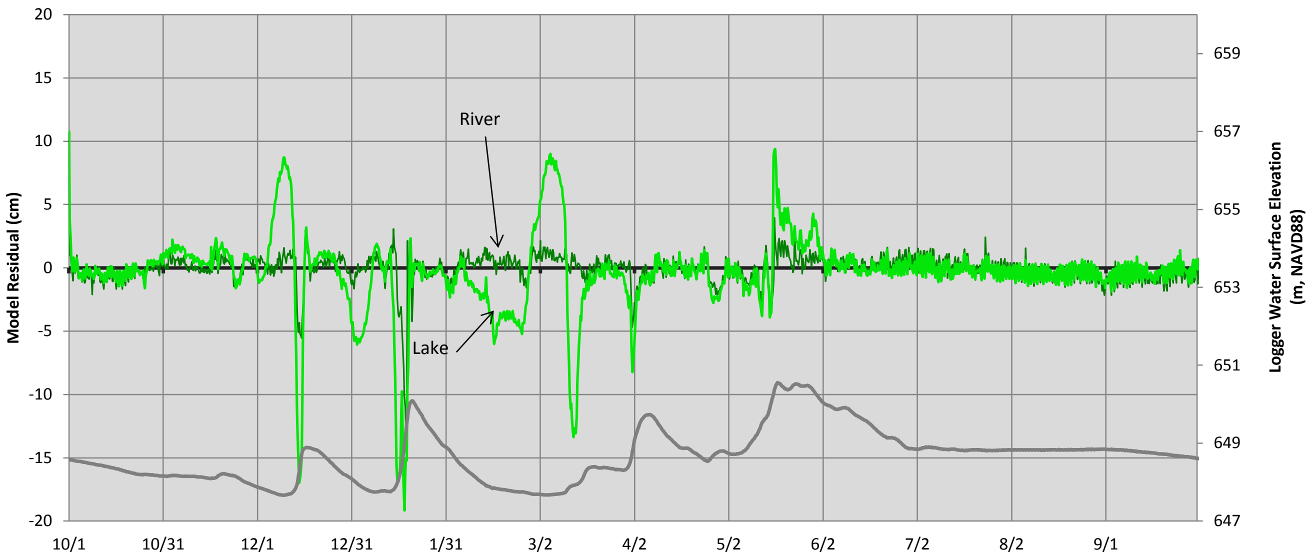


b. River/Lake Exchange

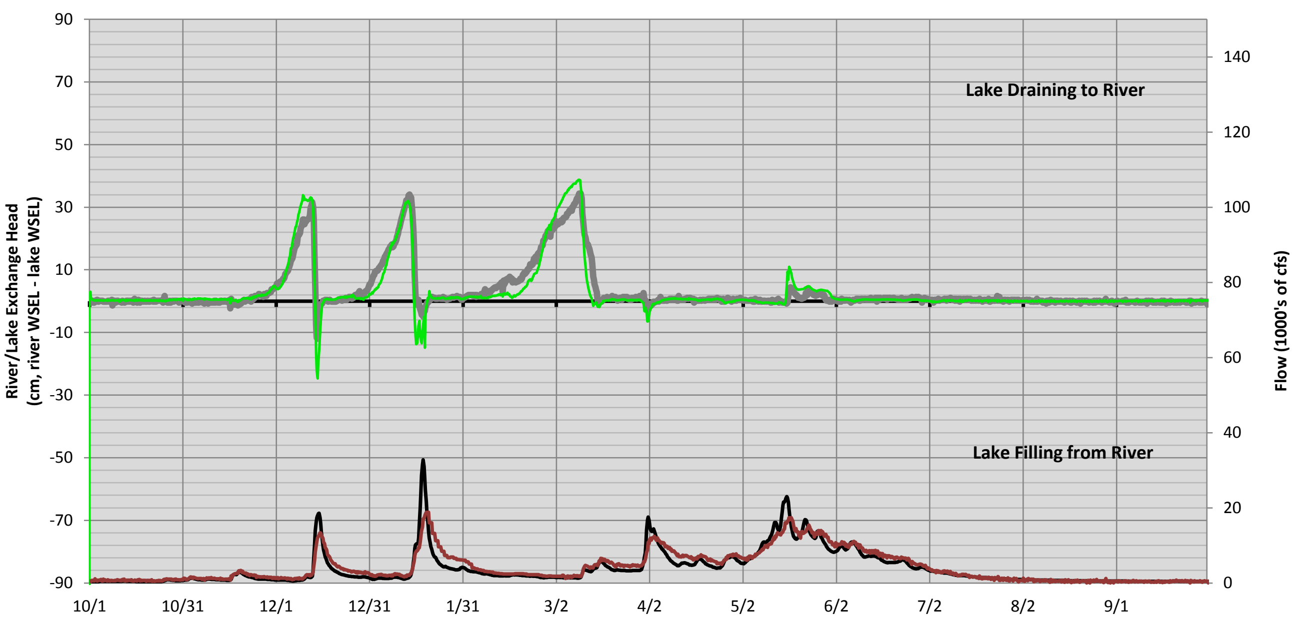
Legend

Logger	Harrison Flow
Cataldo Flow	Thompson Lake - River Logger
Thompson Lake - Lake Logger	

Exhibit 3p-*v*
Thompson Lake Residual and Exchange
WY 2012 (Validation)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



a. River and Lake Logger Residual

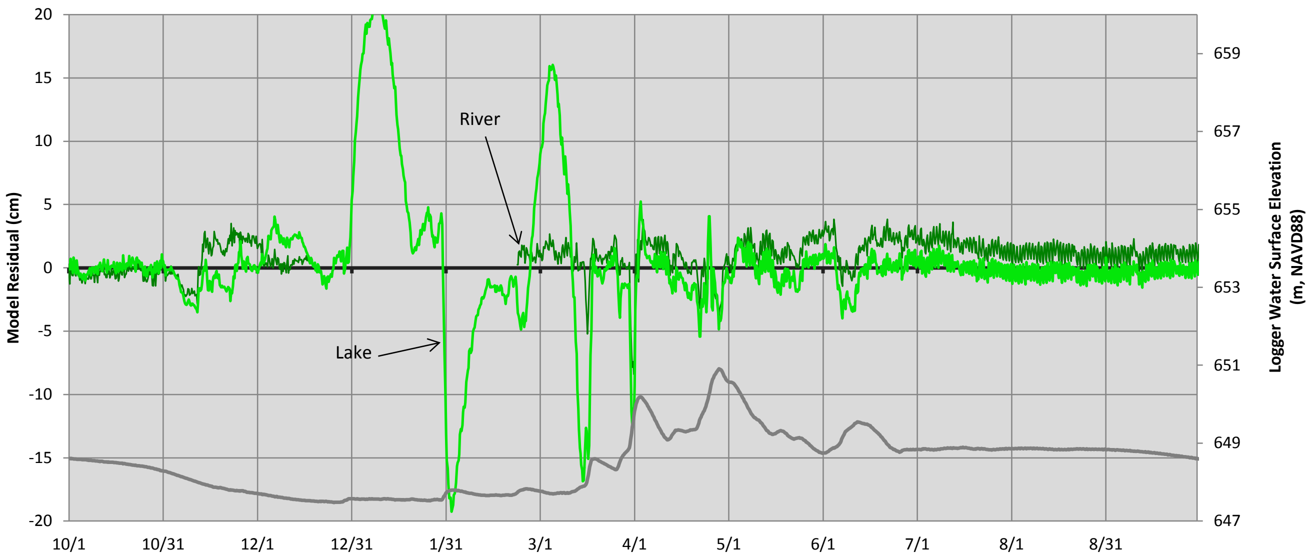


b. River/Lake Exchange

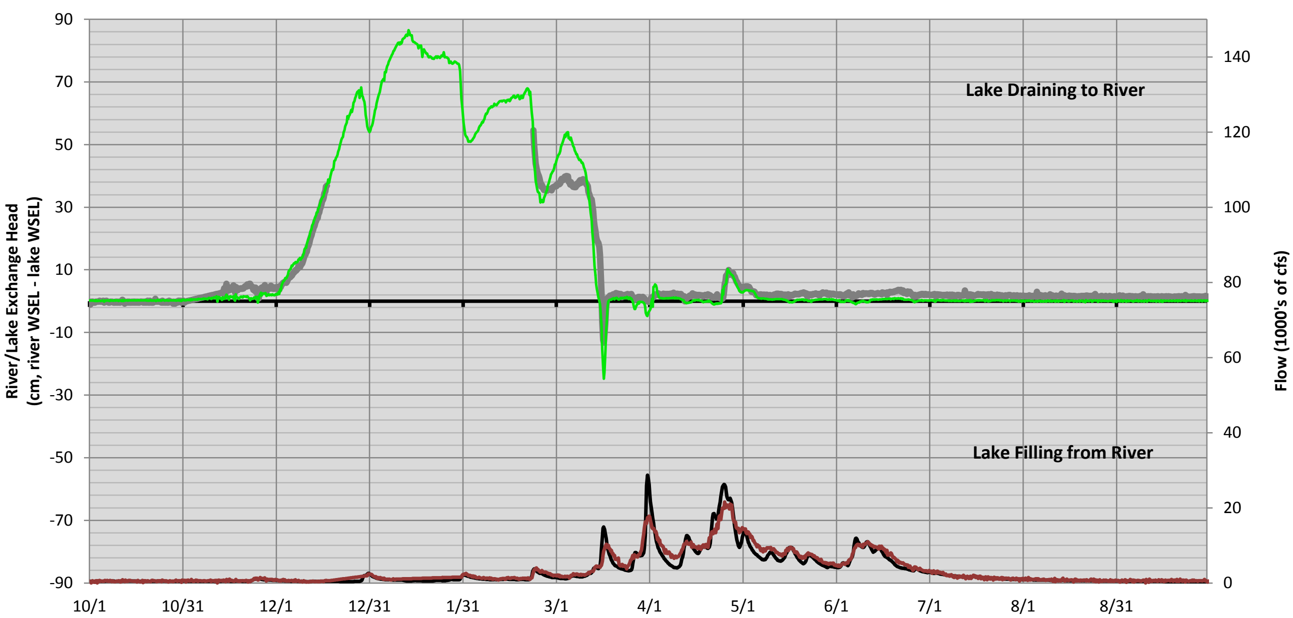
Legend

Logger	Harrison Flow	Cataldo Flow
Blue Lake - River Logger	Blue Lake - Lake Logger	

Exhibit 3c-*c*
BlueLake Residual and Exchange
WY 2011 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

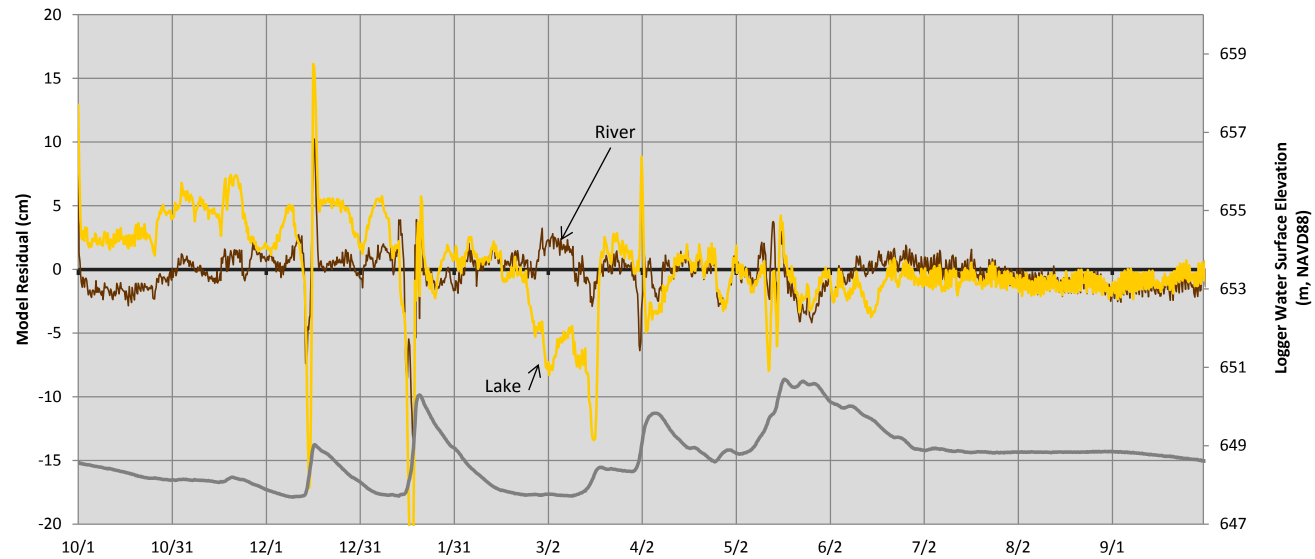


a. River and Lake Logger Residual

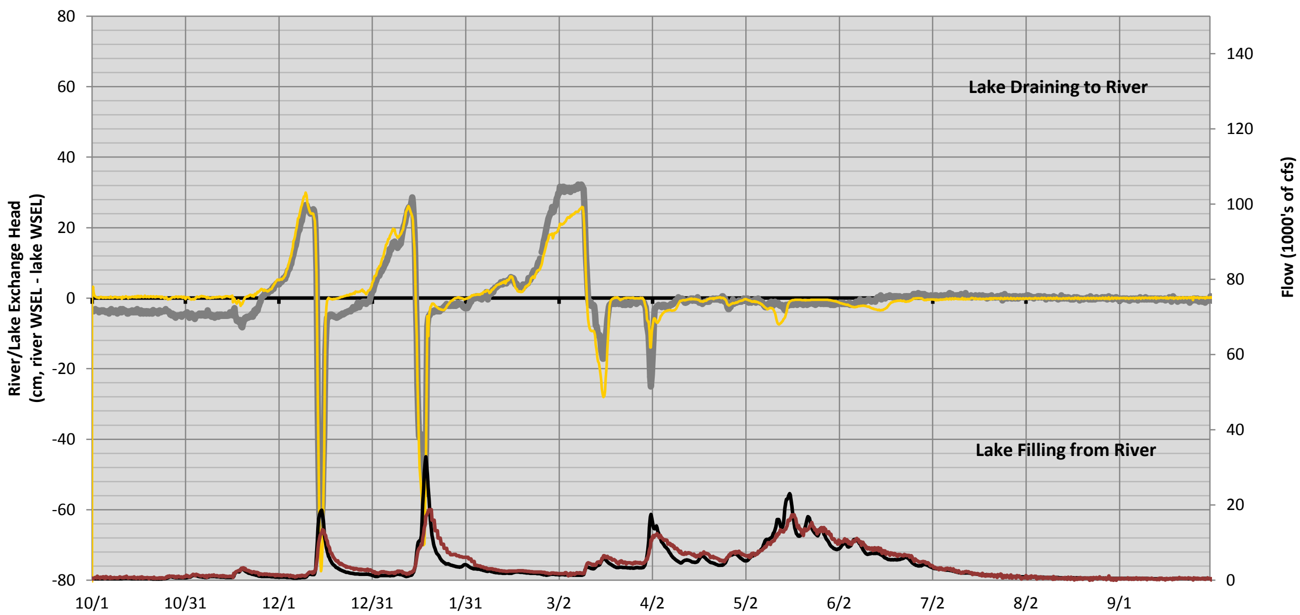


b. River/Lake Exchange

Exhibit 3c-*v*
BlueLake Residual and Exchange
WY 2012 (Validation)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



a. River and Lake Logger Residual



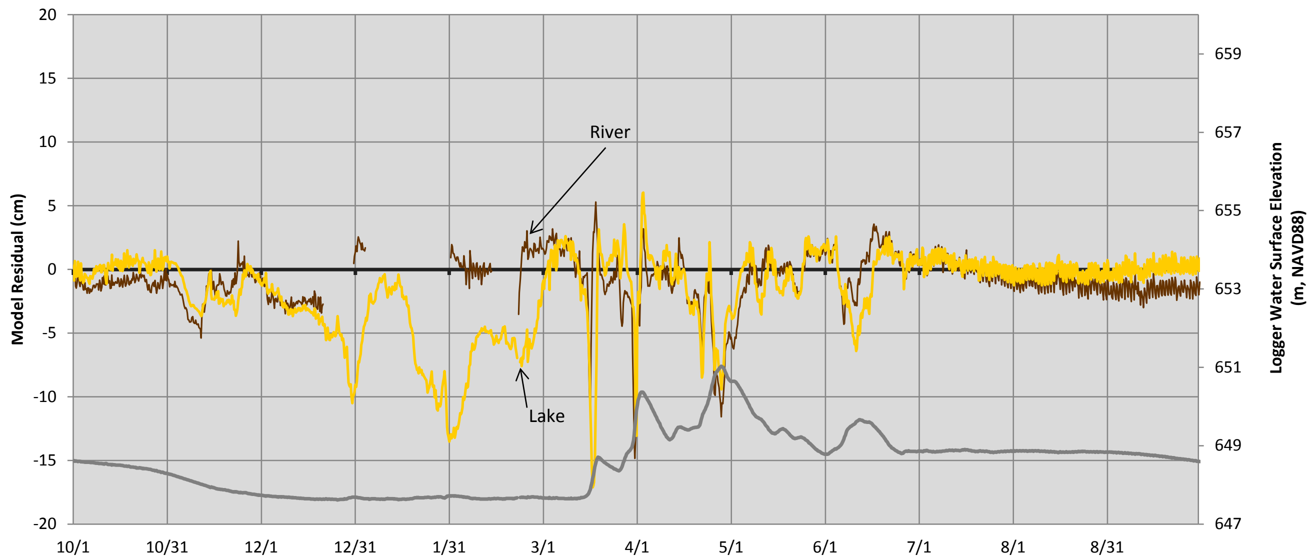
b. River/Lake Exchange

Legend

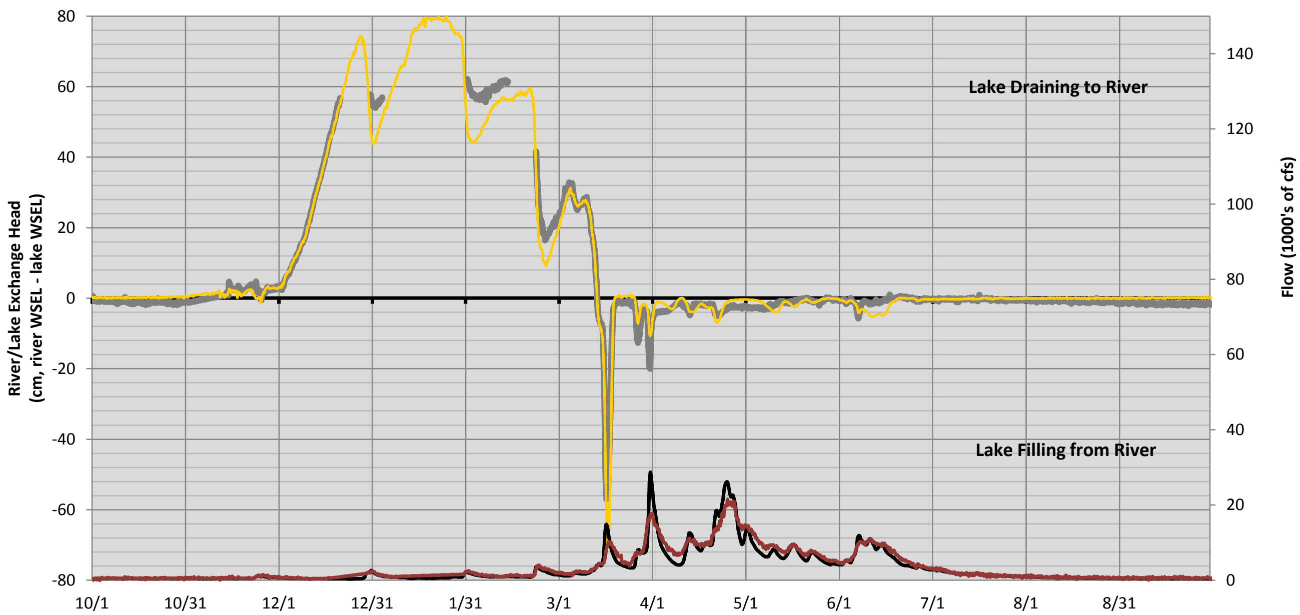
Logger — Harrison Flow — Cataldo Flow

Swan Lake - River Logger — Swan Lake - Lake Logger

Exhibit 3T-*c*
Swan Lake Residual and Exchange
WY2011 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

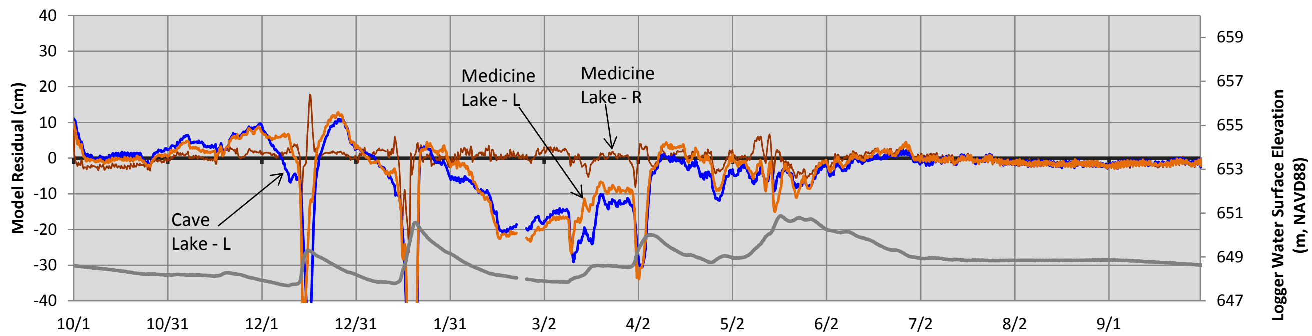


a. River and Lake Logger Residual

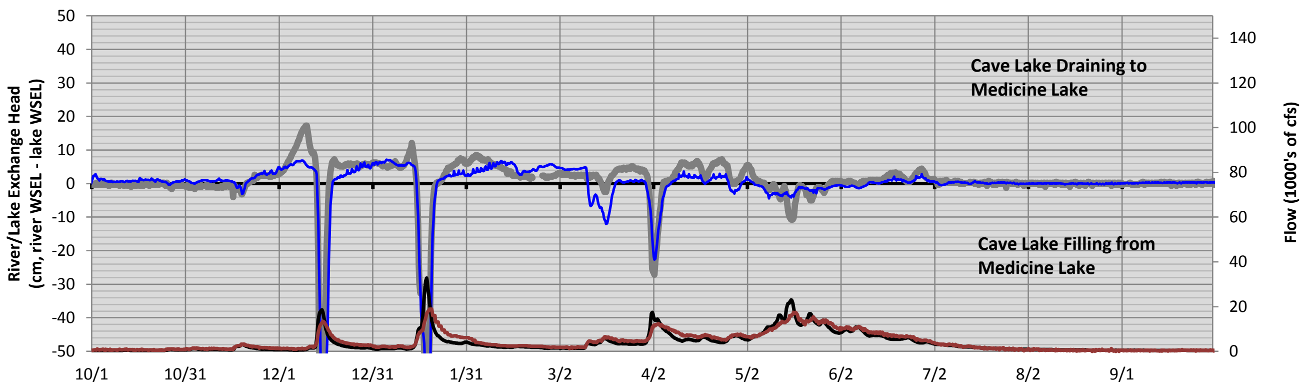


b. River/Lake Exchange

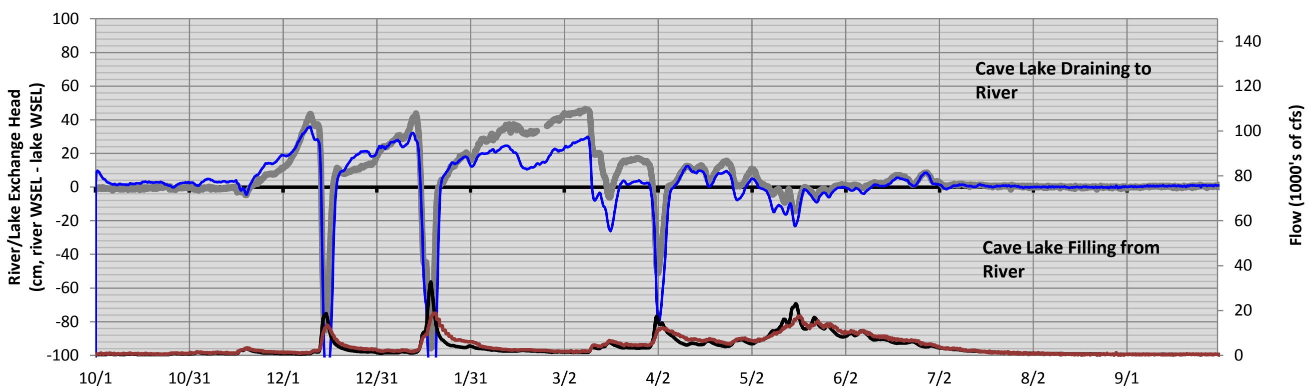
Exhibit 3T-*v*
Swan Lake Residual and Exchange
WY2012 (Validation)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



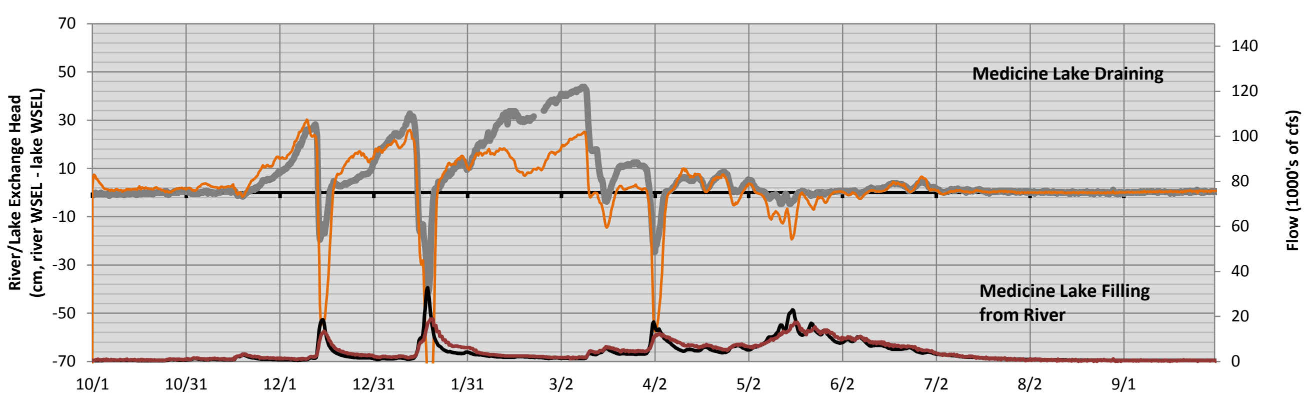
a. River and Lake Logger Residual



b. Cave Lake Exchange with Medicine Lake



c. Cave Lake Exchange with River



e. Medicine Lake Exchange with River

Legend

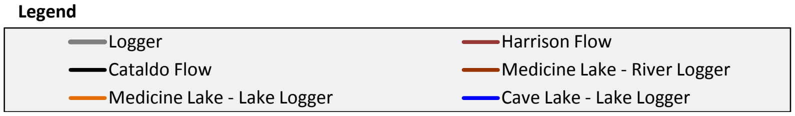
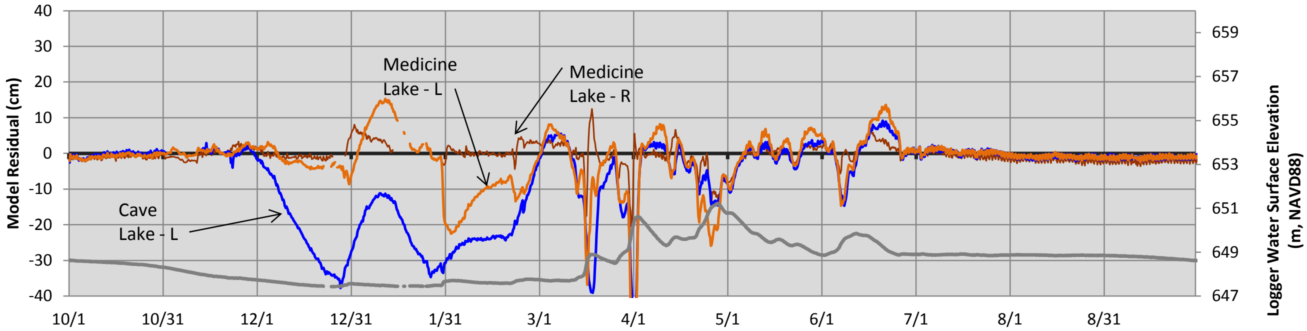
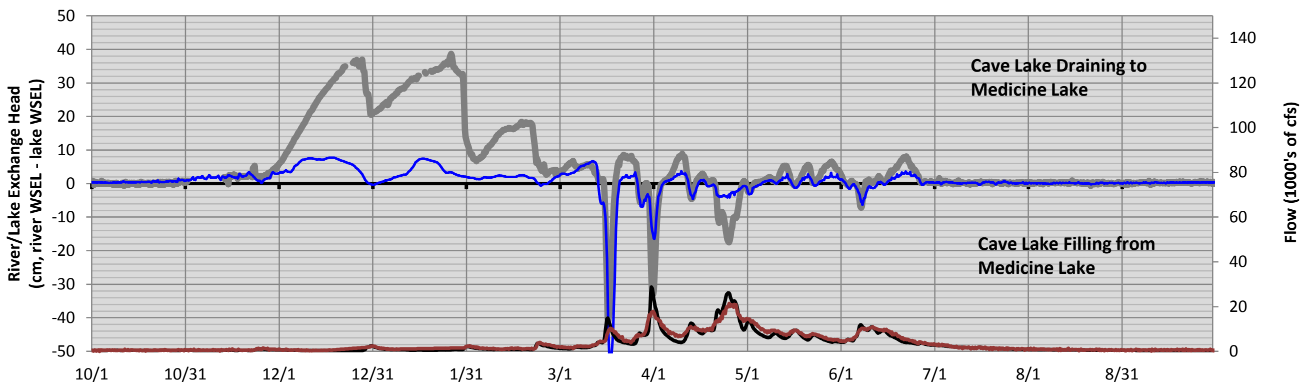


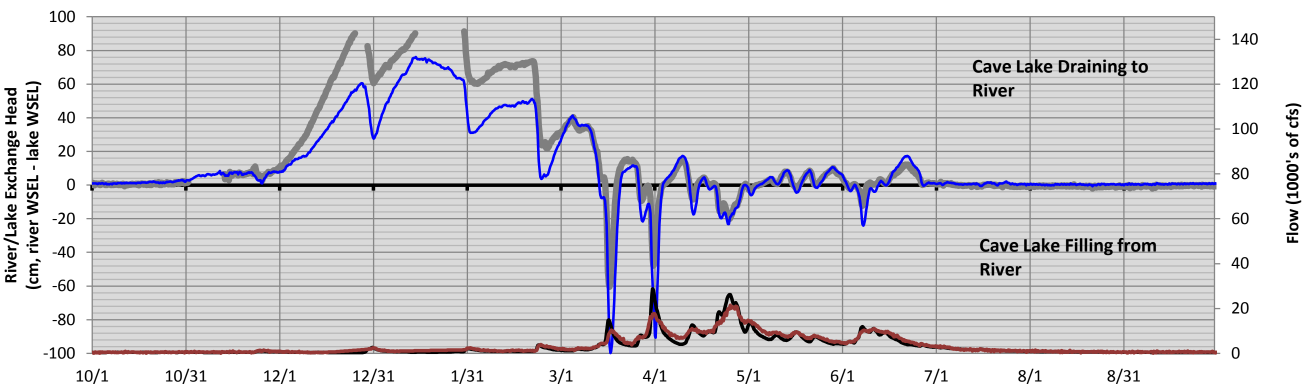
Exhibit 38-*c*
Medicine and Cave Lake Residual and Exchange
WY 2011 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



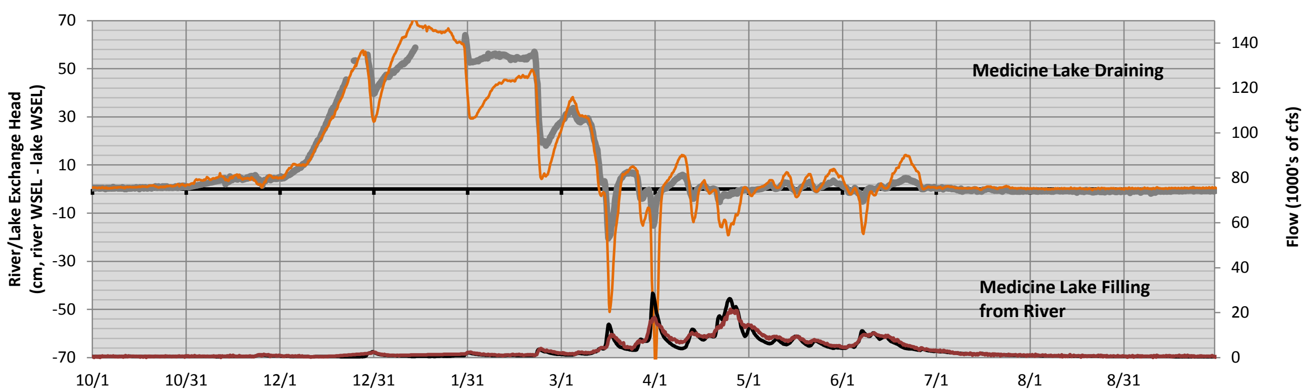
a. River and Lake Logger Residual



b. Cave Lake Exchange with Medicine Lake



c. Cave Lake Exchange with River

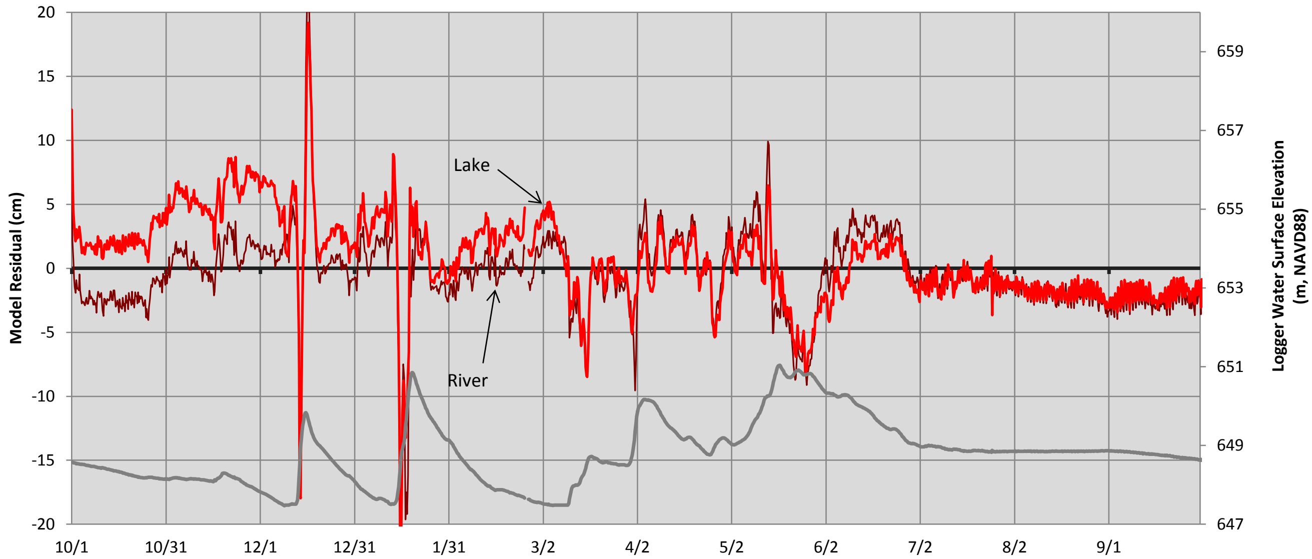


e. Medicine Lake Exchange with River

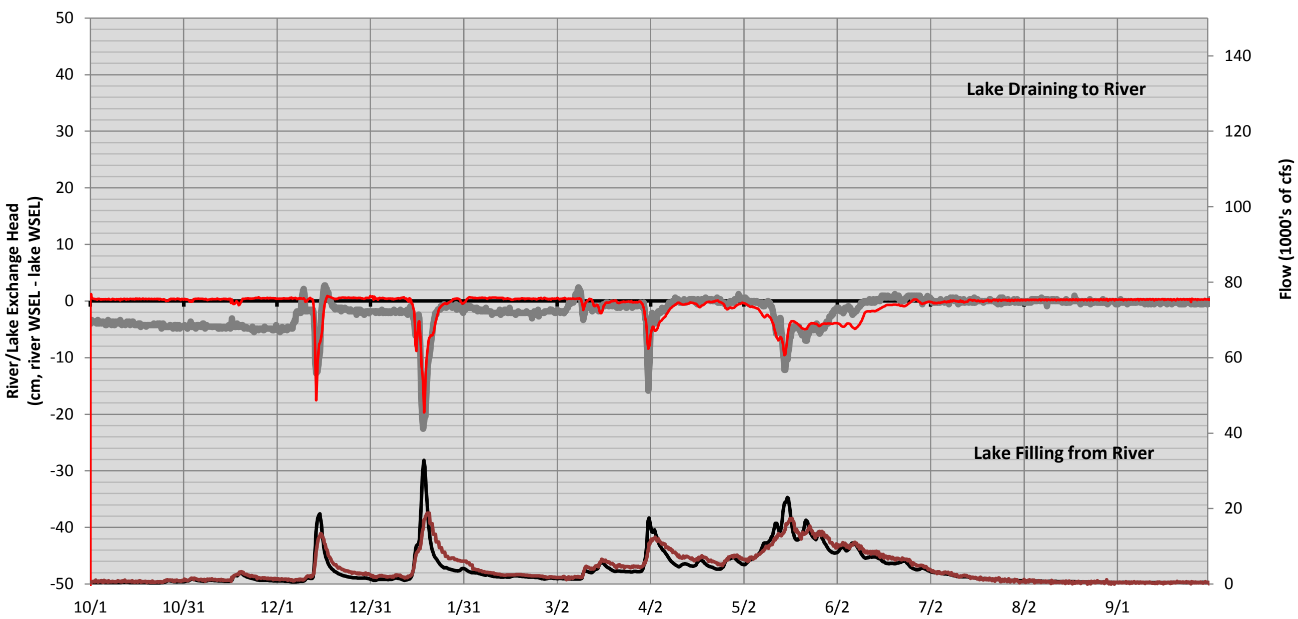
Legend

Logger	Harrison Flow
Cataldo Flow	Medicine Lake - River Logger
Medicine Lake - Lake Logger	Cave Lake - Lake Logger

Exhibit 38-*v*
Medicine and Cave Lake Residual and Exchange
WY 2012 (Validation
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



a. River and Lake Logger Residual

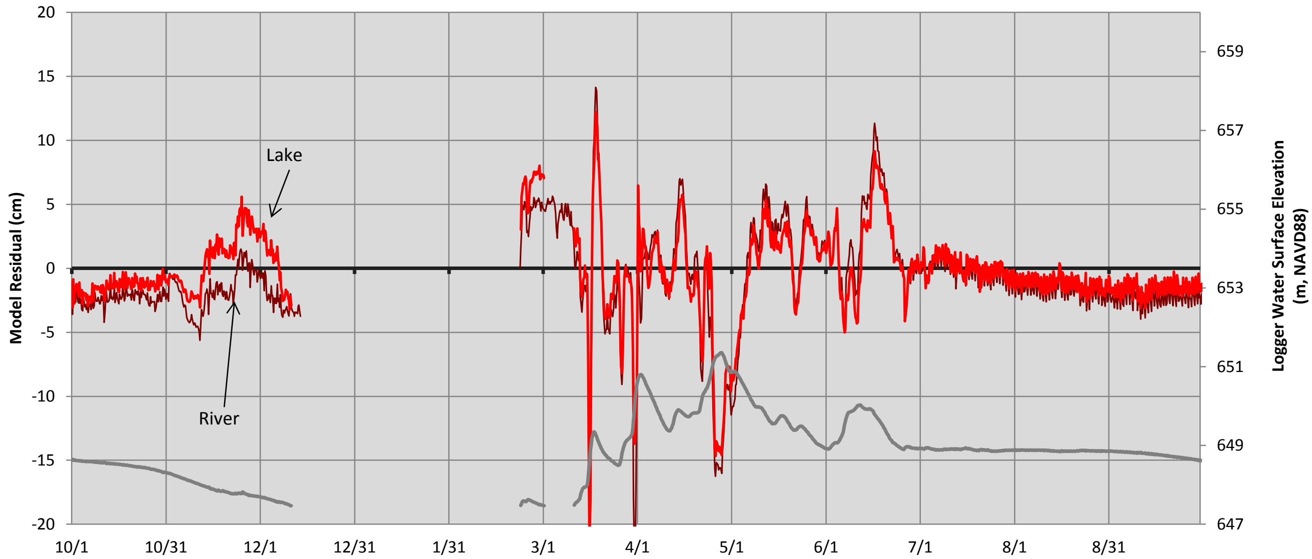


b. River/Lake Exchange

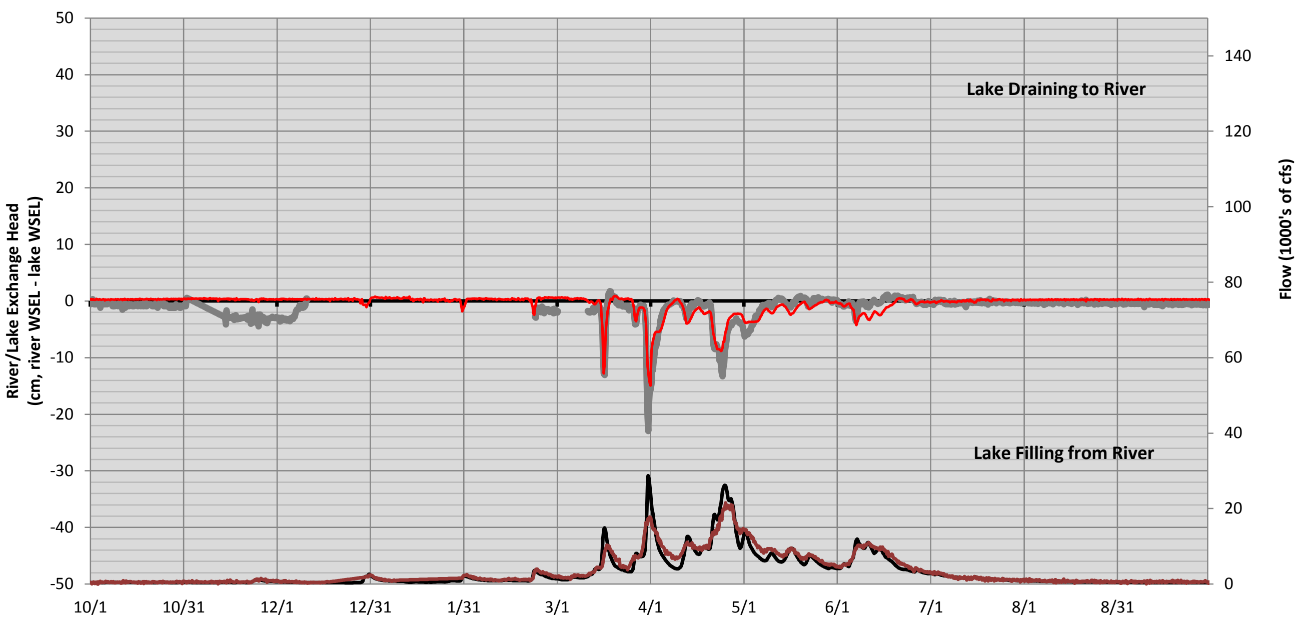
Legend

Logger	Harrison Flow
Cataldo Flow	Killarney Lake - River Logger
Killarney Lake - Lake Logger	

Exhibit 39-*c*
Killarney Lake Residual and Exchange
WY 2011 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



a. River and Lake Logger Residual

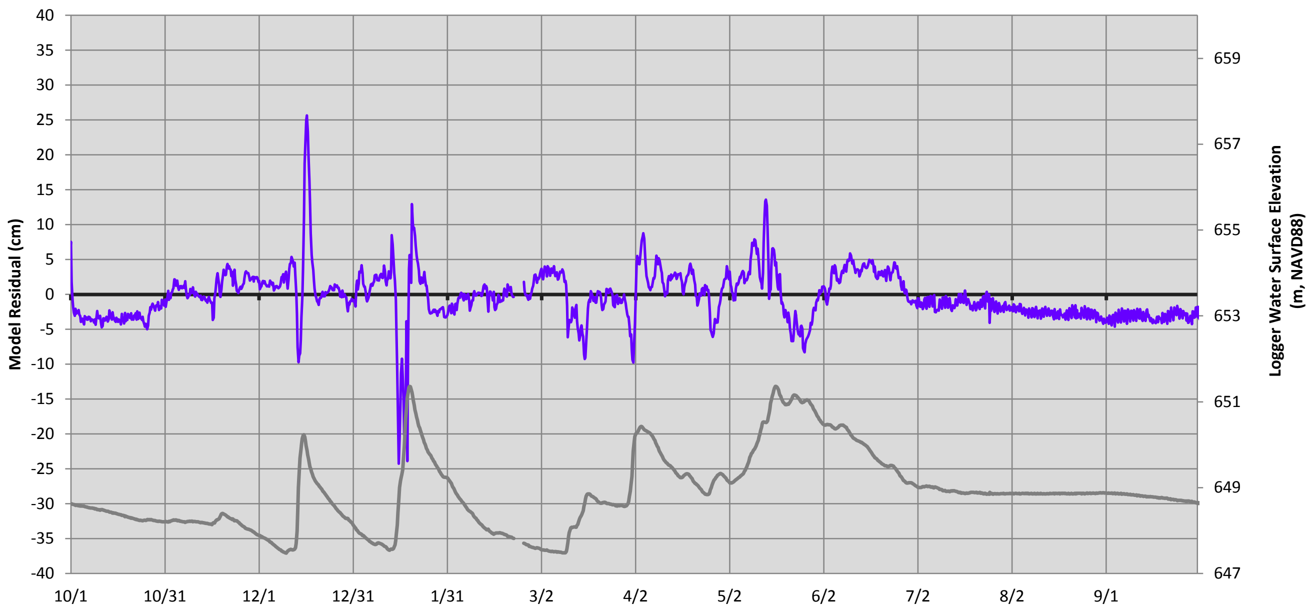


b. River/Lake Exchange

Legend

Logger	Harrison Flow
Cataldo Flow	Killarney Lake - River Logger
Killarney Lake - Lake Logger	

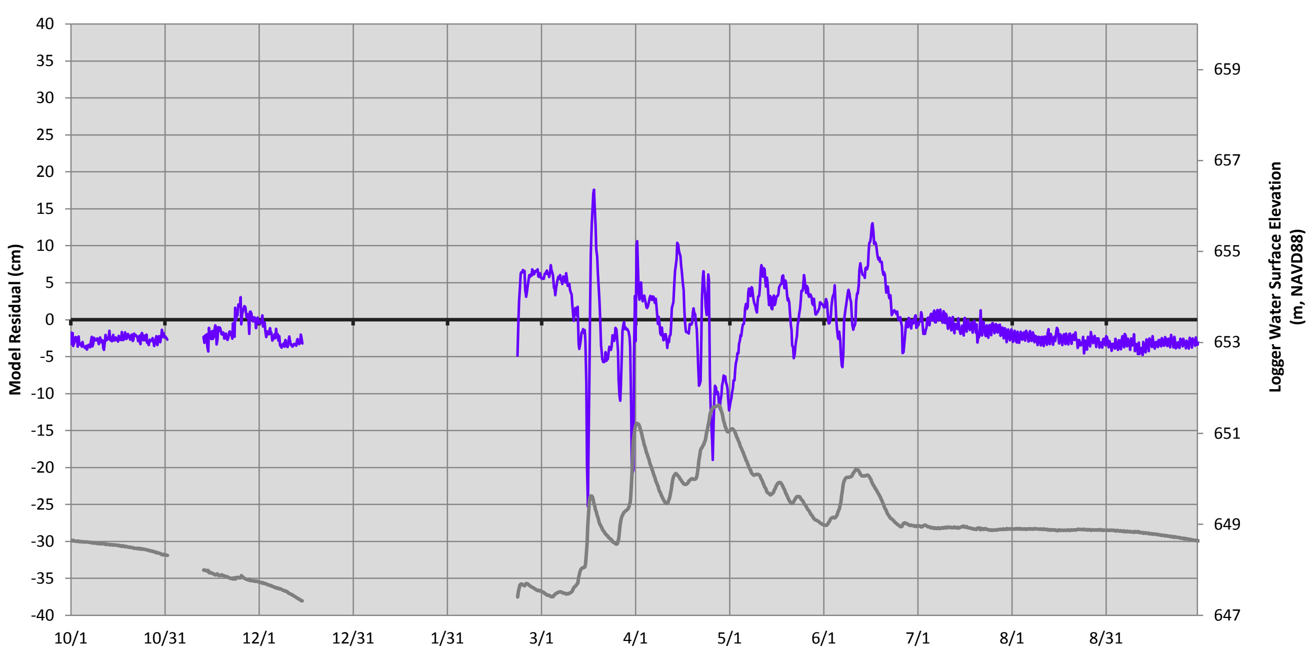
Exhibit 39-*v*
Killarney Lake Residual and Exchange
WY 2012 (Validation)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Legend

Logger WSEL   Black Rock - River Logger

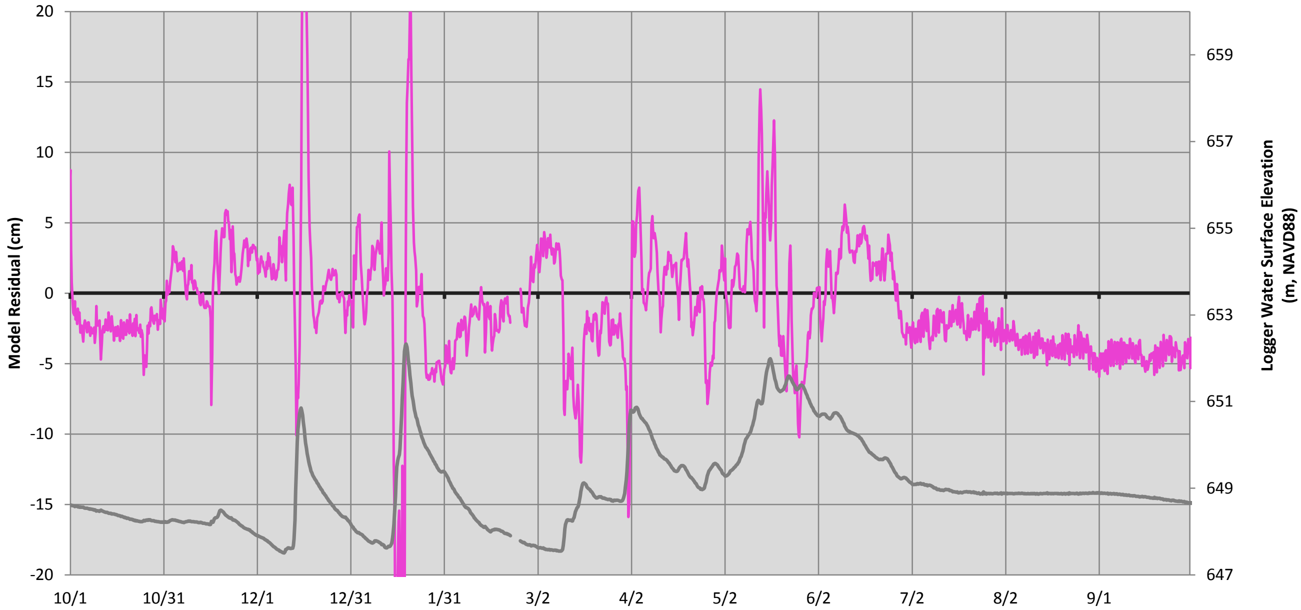
Exhibit 40-*c*
Black Rock River Logger Residual
WY 2011 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Legend

Logger WSEL   Black Rock - River Logger

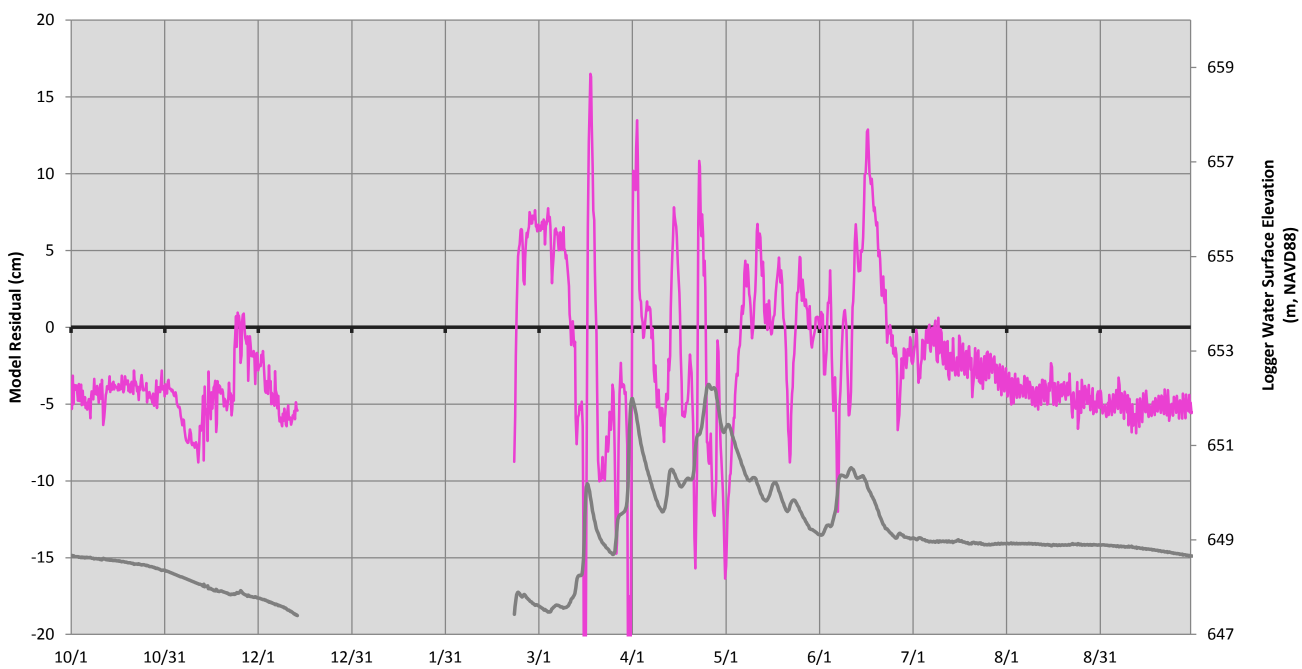
Exhibit 40-*v*
Black Rock River Logger Residual
WY 2012 (Validation)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Legend

Logger WSEL — Dudley - River Logger

Exhibit 41-*c*
Dudley River Logger Residual
WY 2011 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Legend

Logger WSEL — Dudley - River Logger

Exhibit 41-*v*
Dudley River Logger Residual
WY 2012 (Validation)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

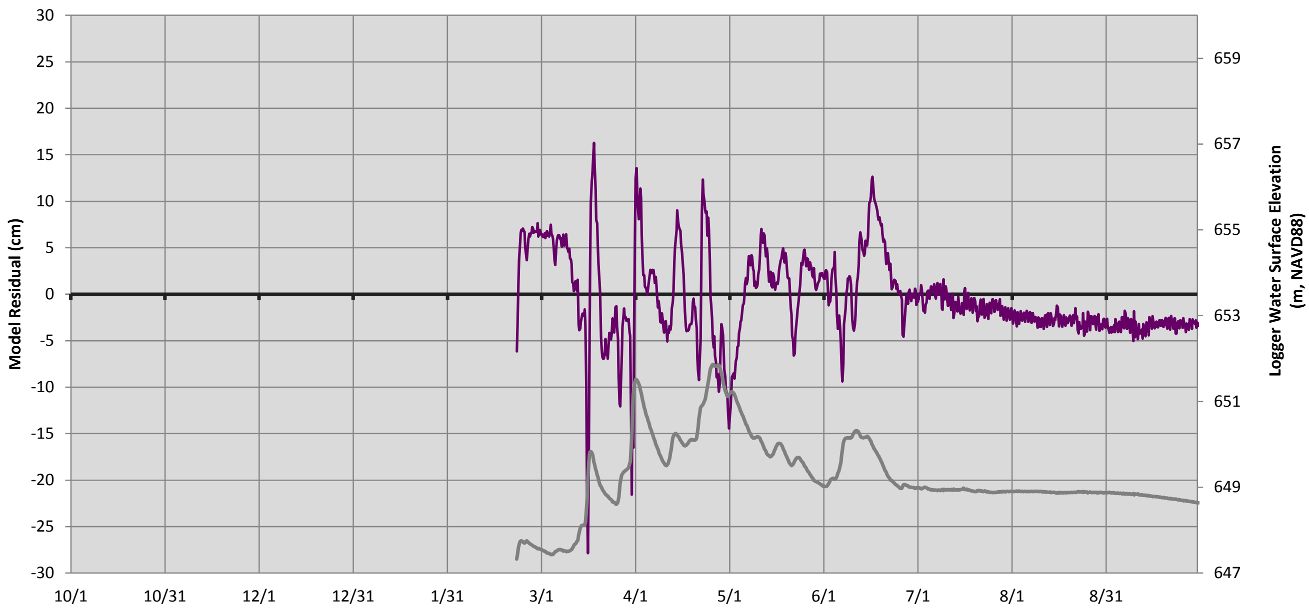


Exhibit 42-*c*
Below Bull Run River Logger Residual
WY 2012 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Legend

Logger WSEL   Below Bull Run - River Logger

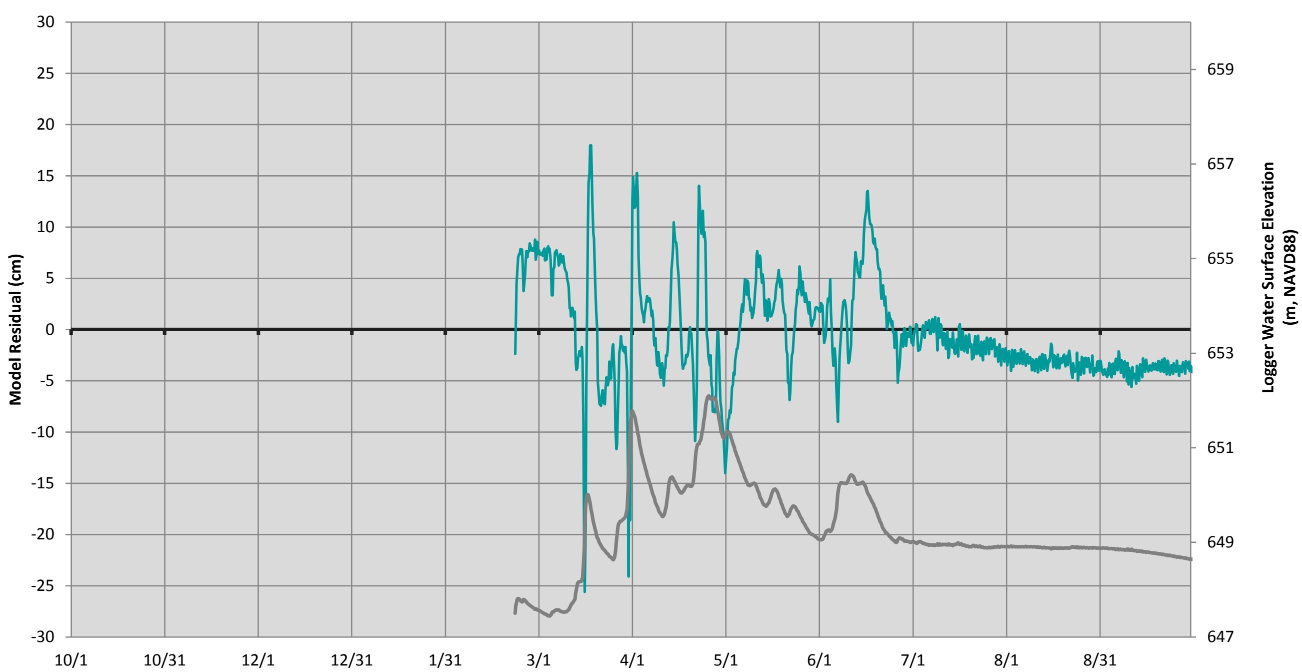


Exhibit 43-*c*
Above Bull Run River Logger Residual
WY 2012 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Legend

Logger WSEL   Above Bull Run - River Logger

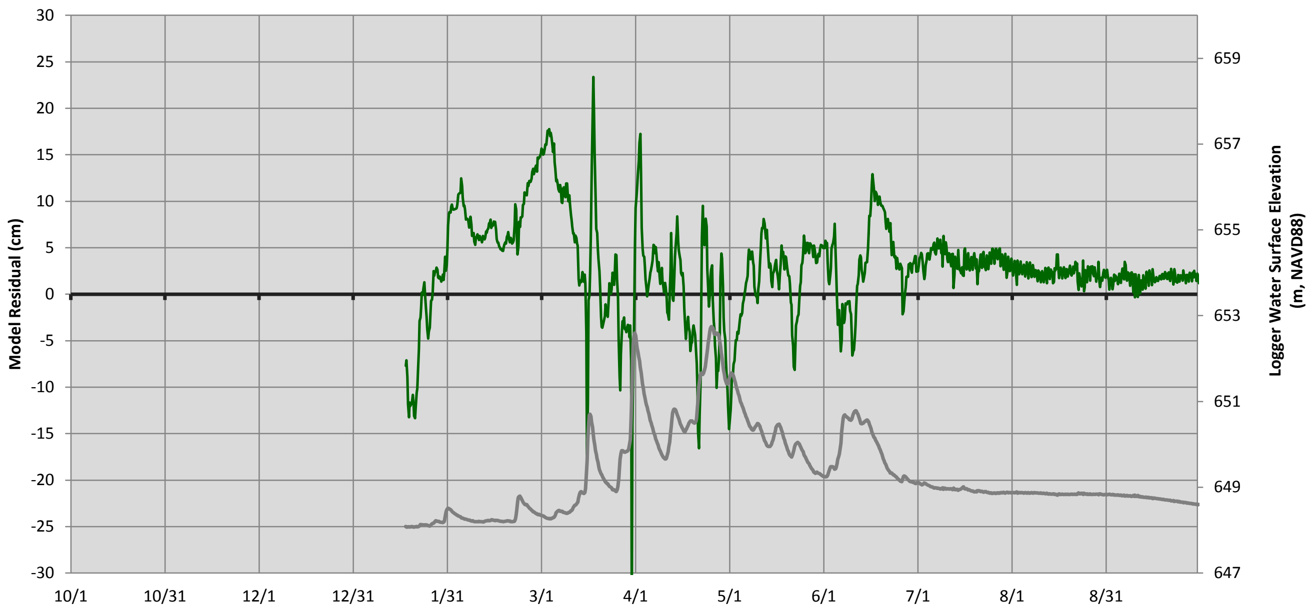


Exhibit 44-*c*
Dredge Pool River Logger Residual
WY 2012 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Legend

Logger WSEL — Dredge Pool - River Logger

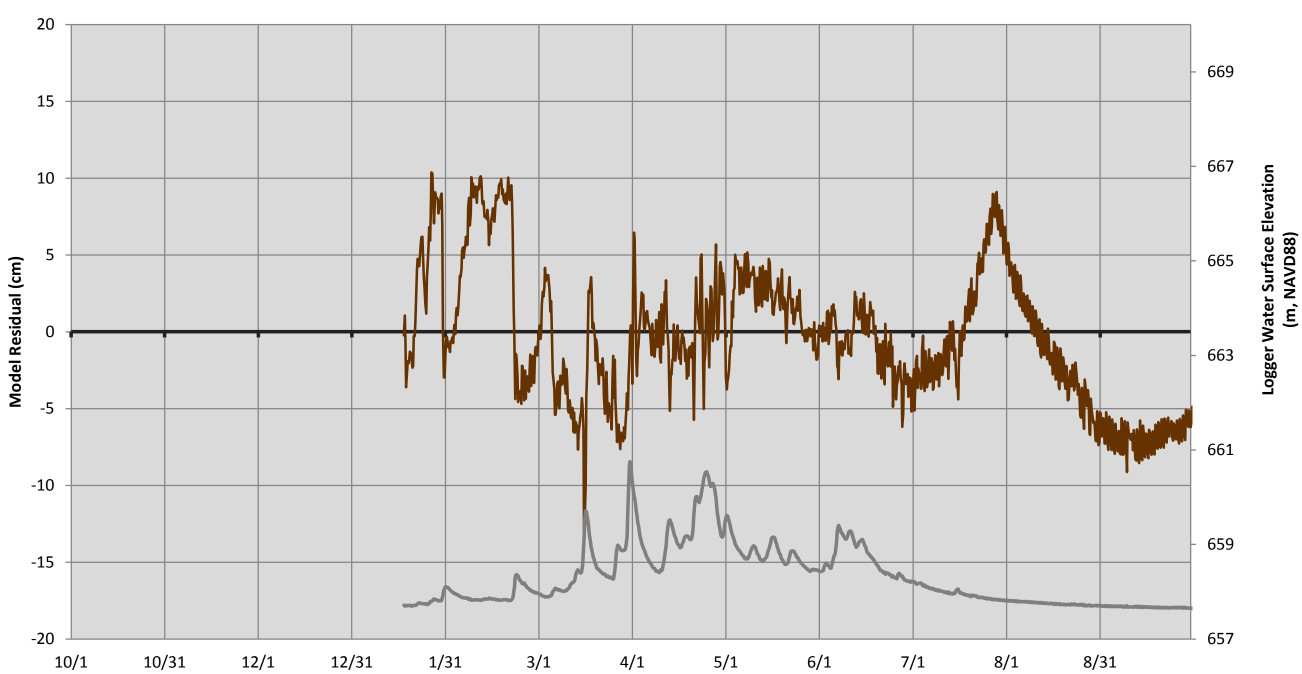


Exhibit 45-*c*
Confluence River Logger Residual
WY 2012 (Calibration)
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Legend

Logger WSEL — Confluence - River Logger

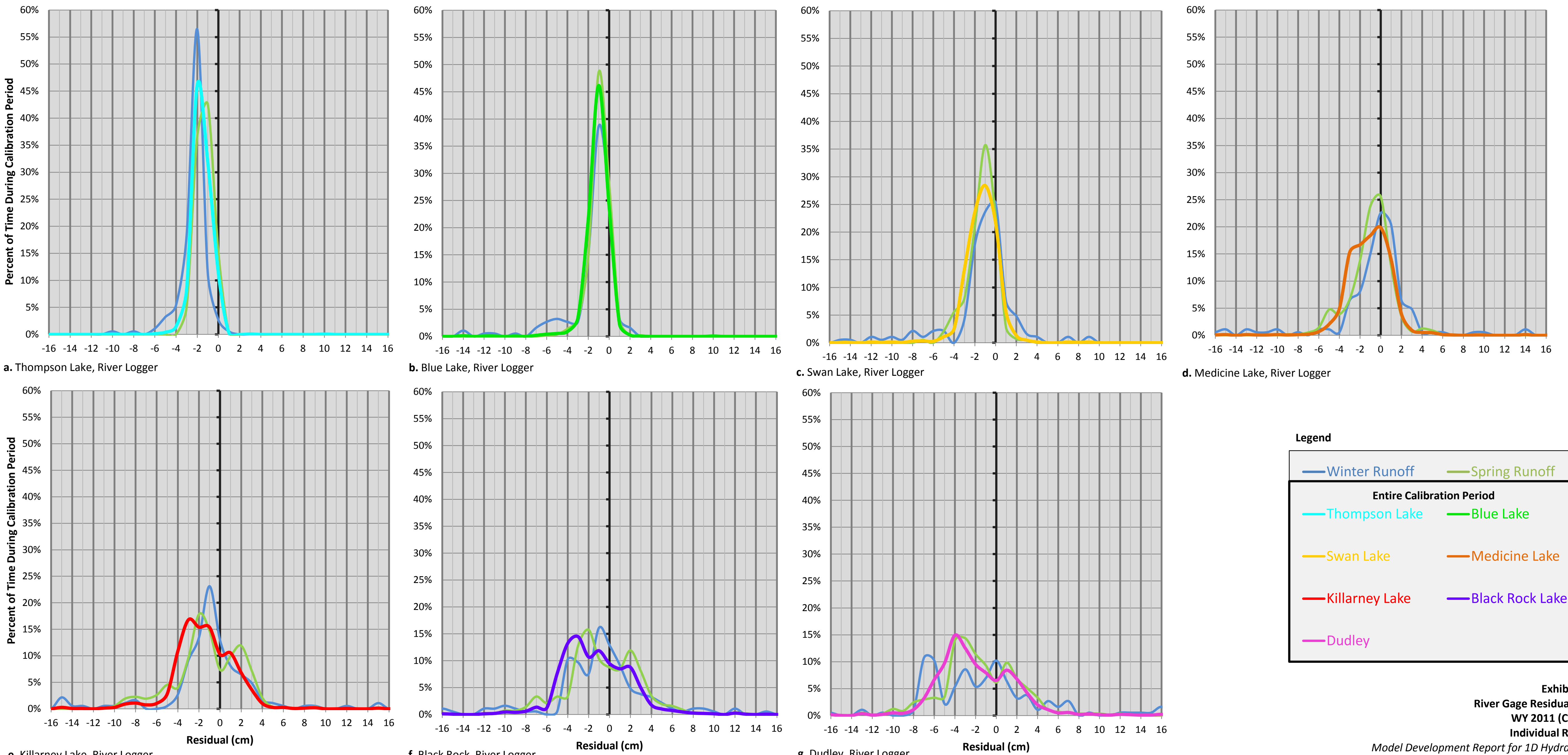
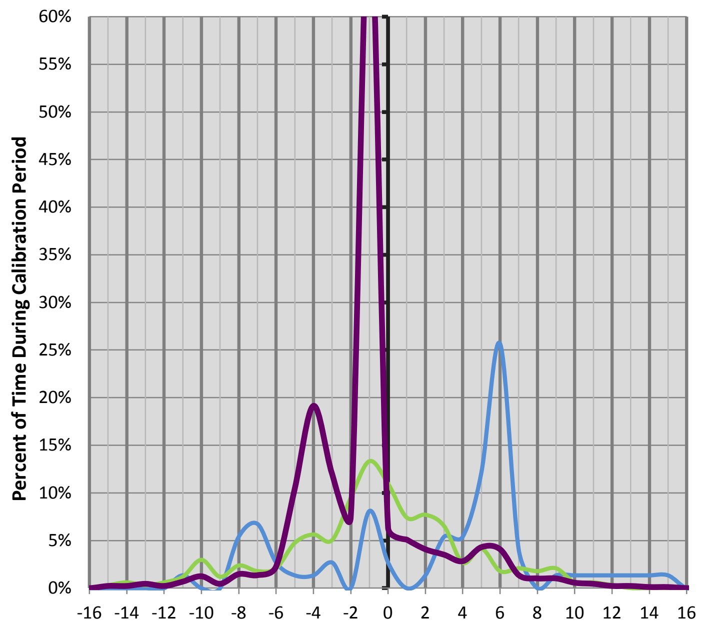
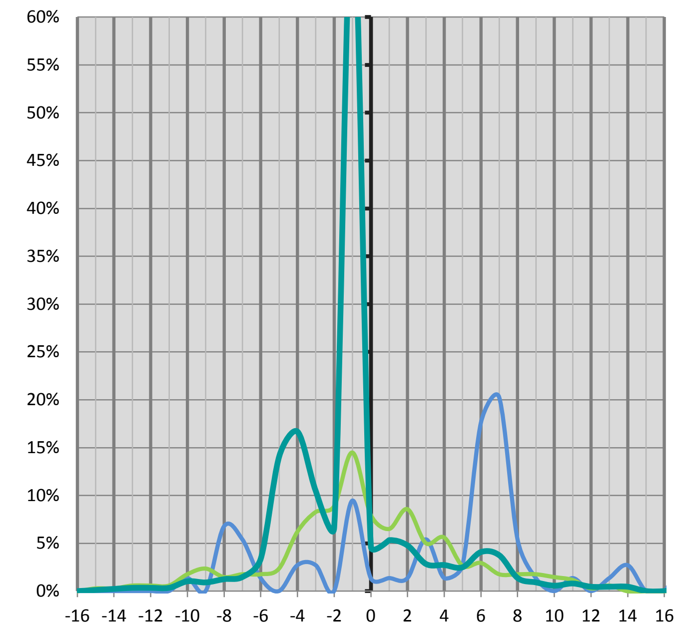


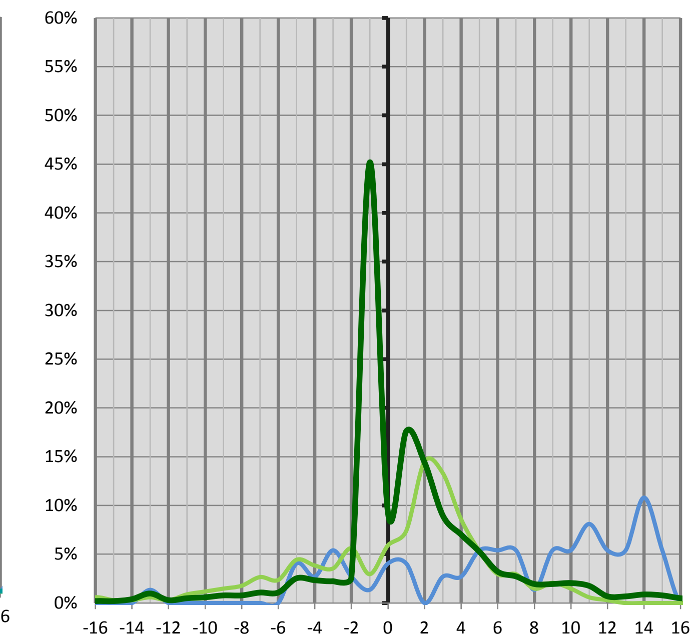
Exhibit 46 -c .a-g
River Gage Residual-Duration
WY 2011 (Calibration)
Individual River Gages
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



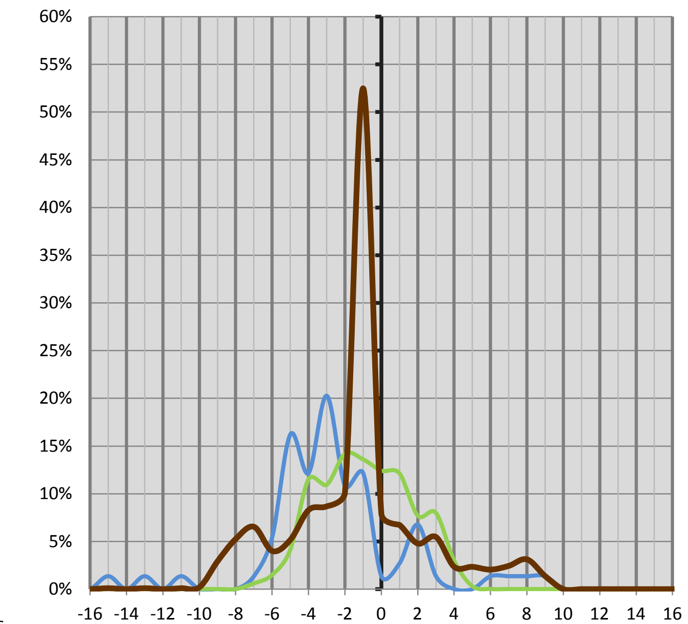
h. Below Bull Run, River Logger



i. Above Bull Run, River Logger



j. Dredge Pool, River Logger



k. Confluence, River Logger

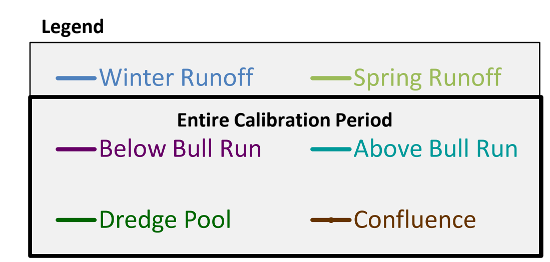
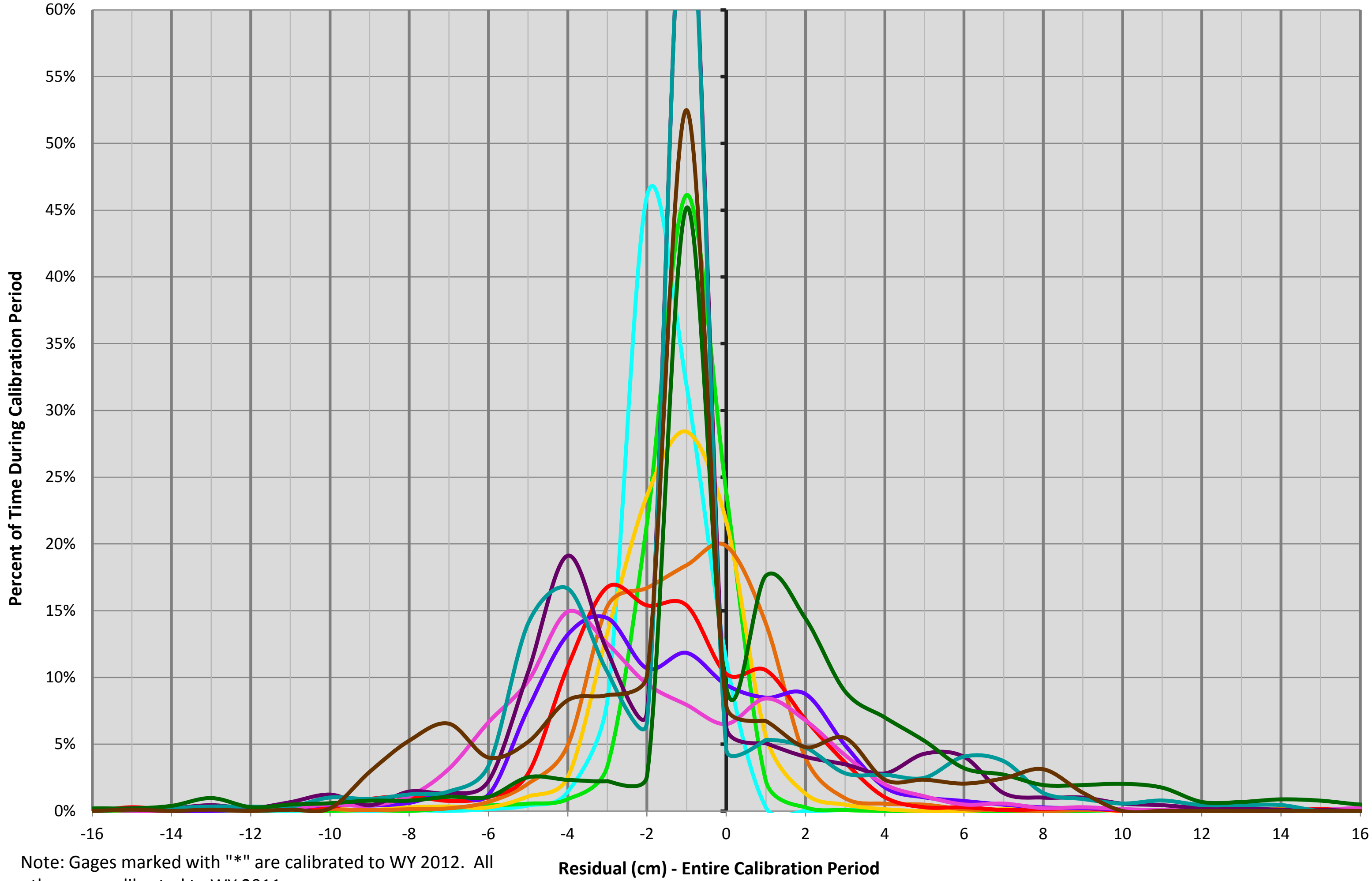


Exhibit 46 -*c* .h-k
River Gage Residual-Duration
WY 2012 (Calibration)
Individual River Gages
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Note: Gages marked with "*" are calibrated to WY 2012. All others are calibrated to WY 2011.

Thompson - R	Blue - R	Swan - R	Medicine - R
Killarney - R	Black Rock - R	Dudley - R	Below Bull Run - R*
Above Bull Run - R*	Dredge Pool - R*	Confluence - R*	

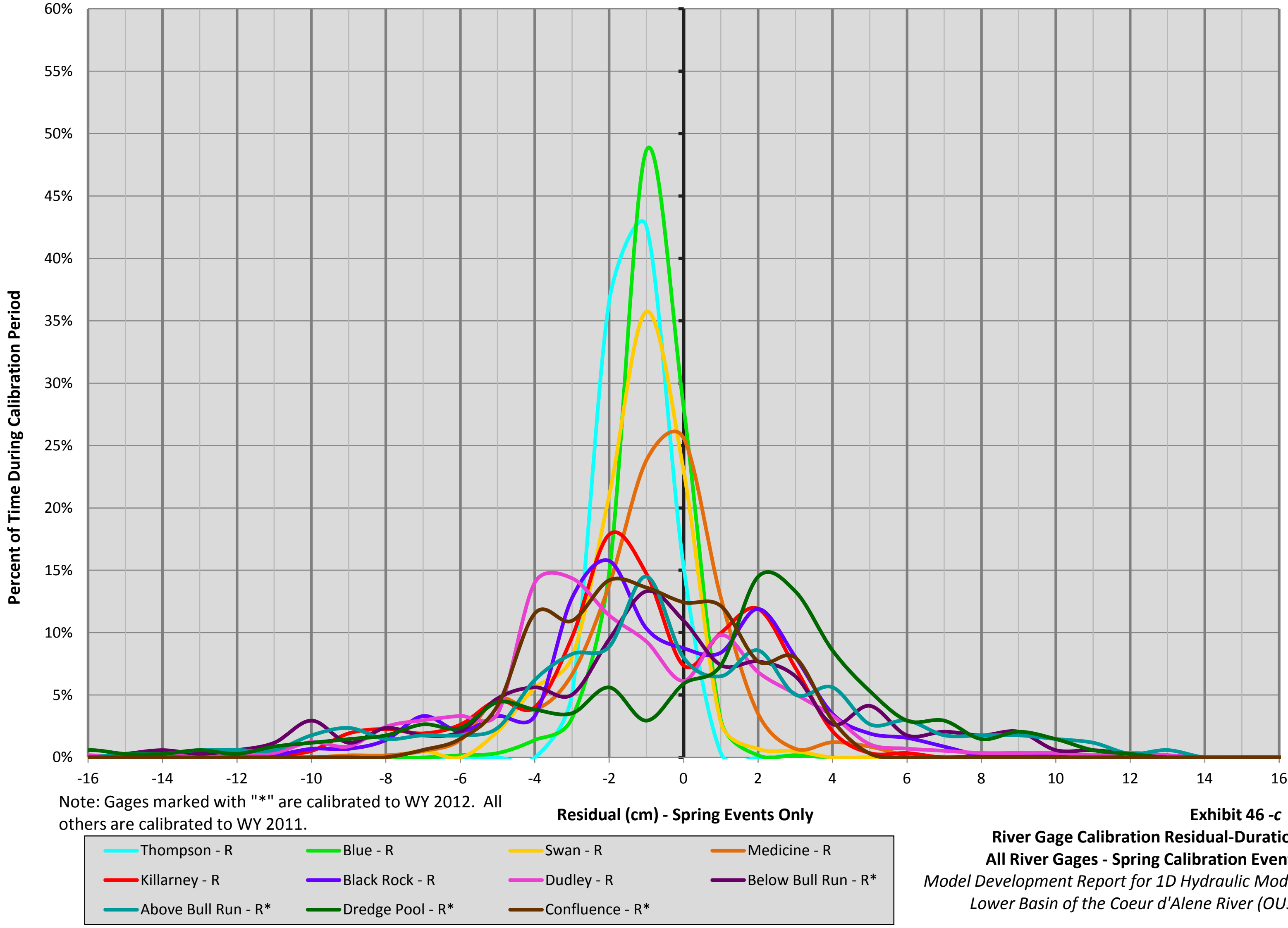
Exhibit 46 -c .l

River Gage Calibration Residual-Duration

All River Gages - Entire Calibration Period

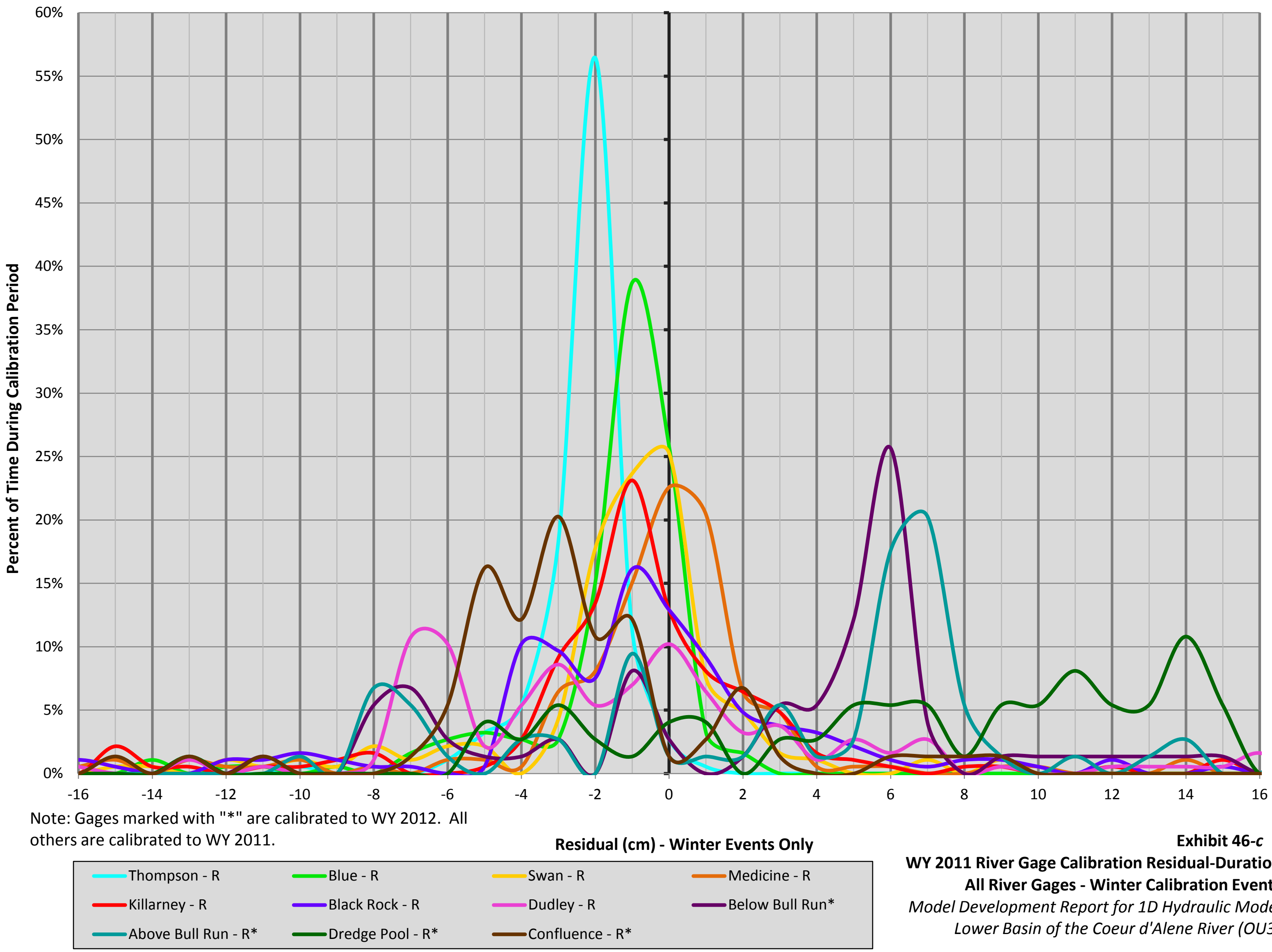
Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)



Note: Gages marked with "*" are calibrated to WY 2012. All others are calibrated to WY 2011.

Exhibit 46 -*c* .m
River Gage Calibration Residual-Duration
All River Gages - Spring Calibration Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Note: Gages marked with "*" are calibrated to WY 2012. All others are calibrated to WY 2011.

Exhibit 46-*c* .n

WY 2011 River Gage Calibration Residual-Duration

All River Gages - Winter Calibration Events

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

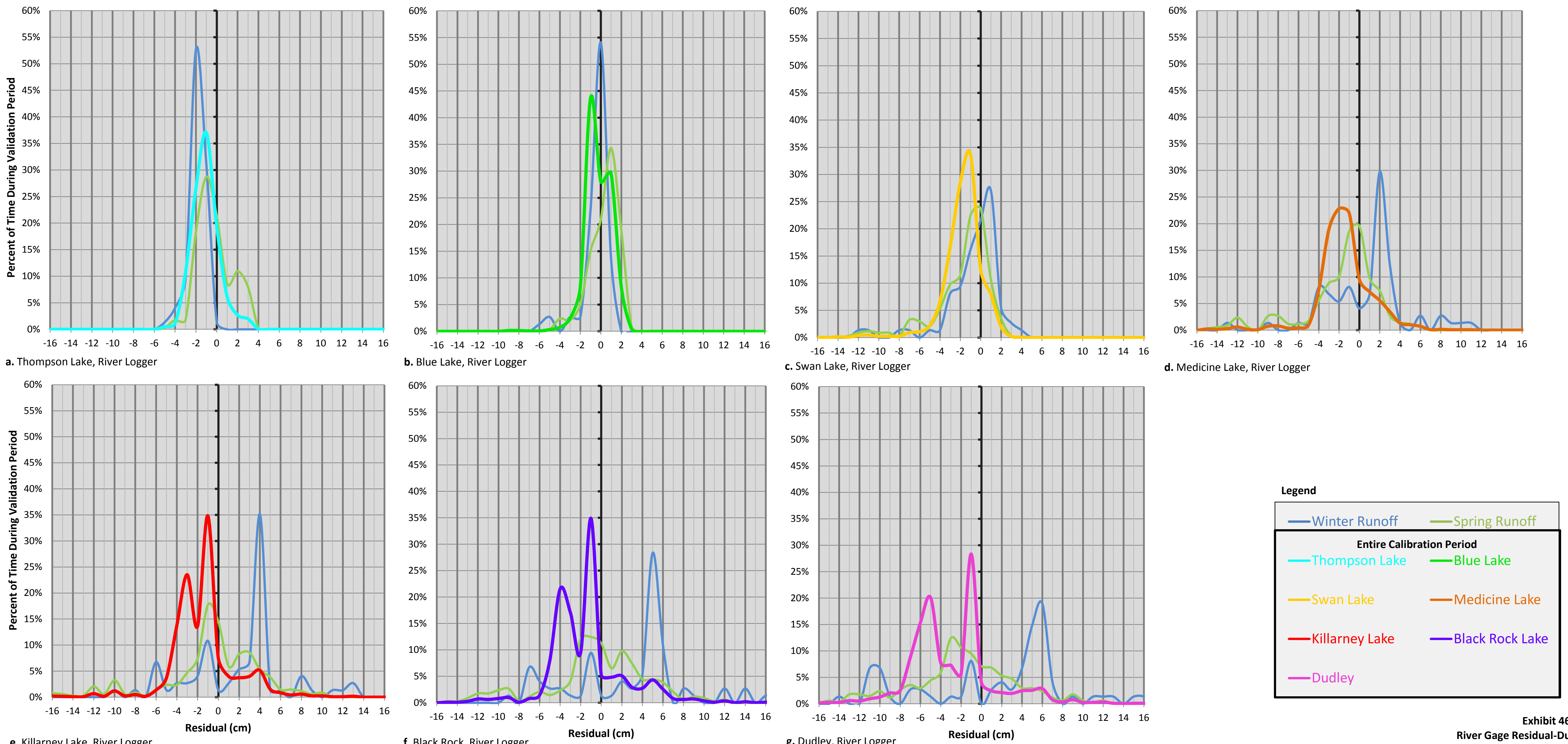
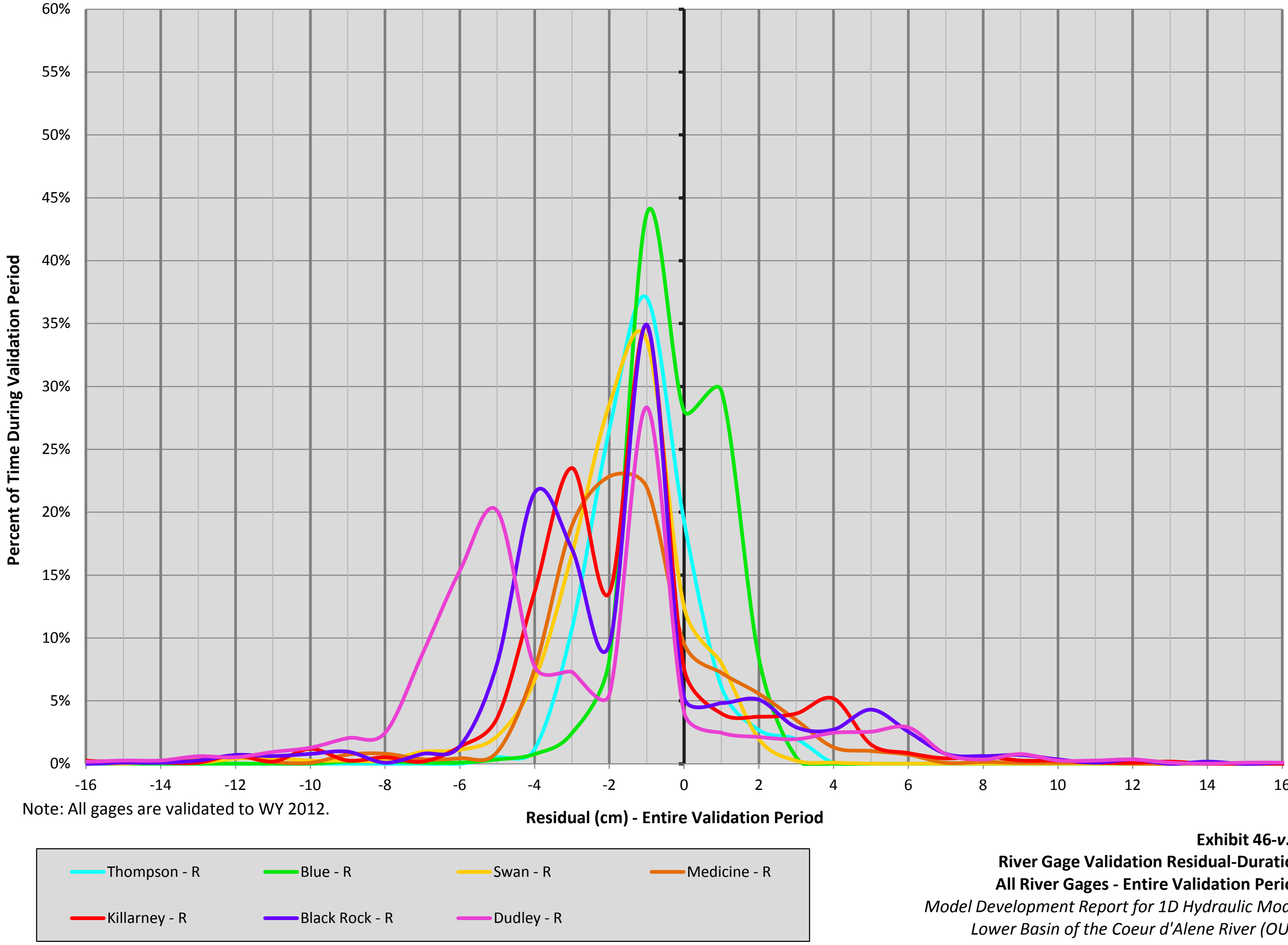
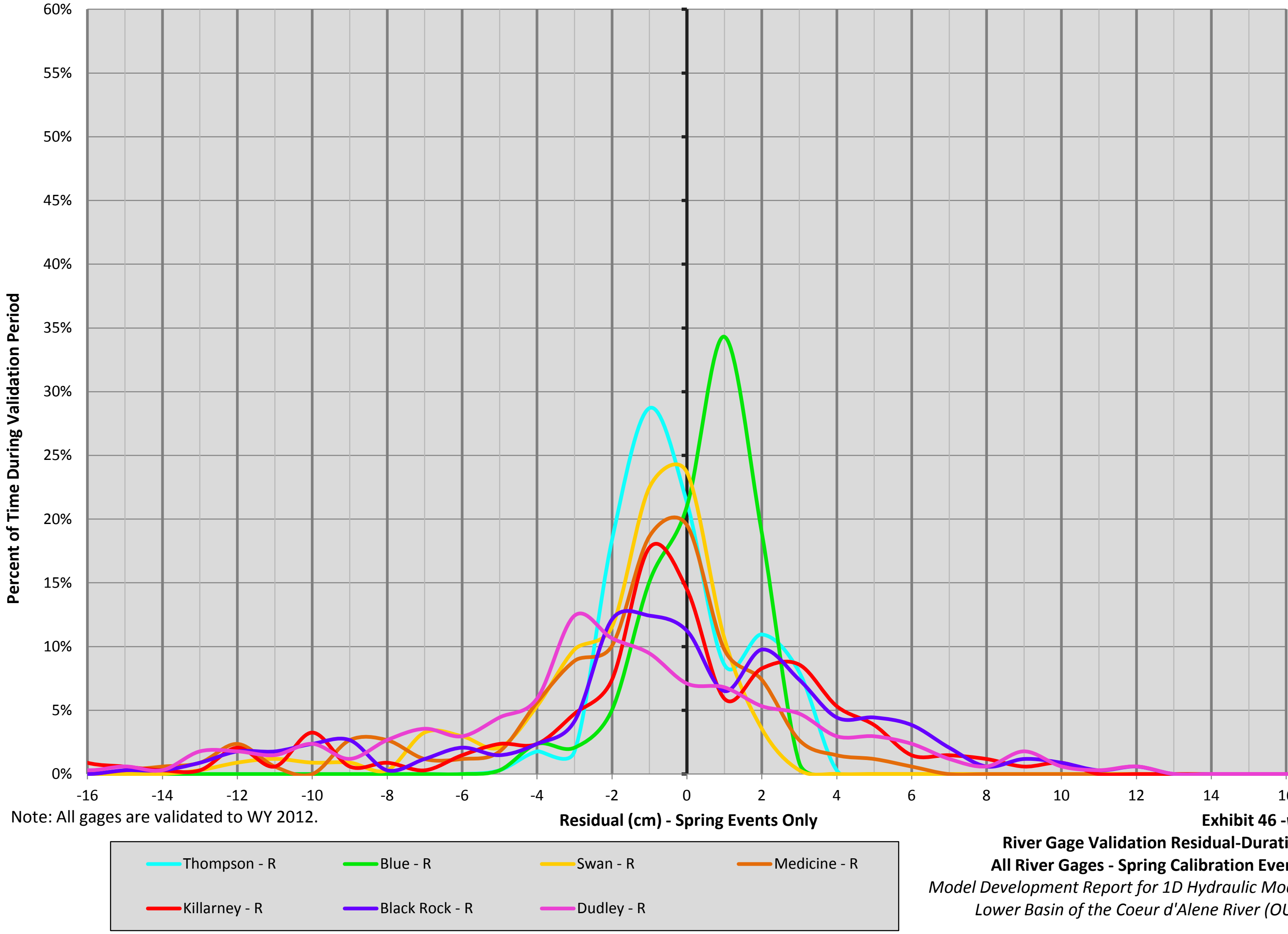


Exhibit 46 -v.a-g
River Gage Residual-Duration
WY 2012 (Validation)
Individual River Gages
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



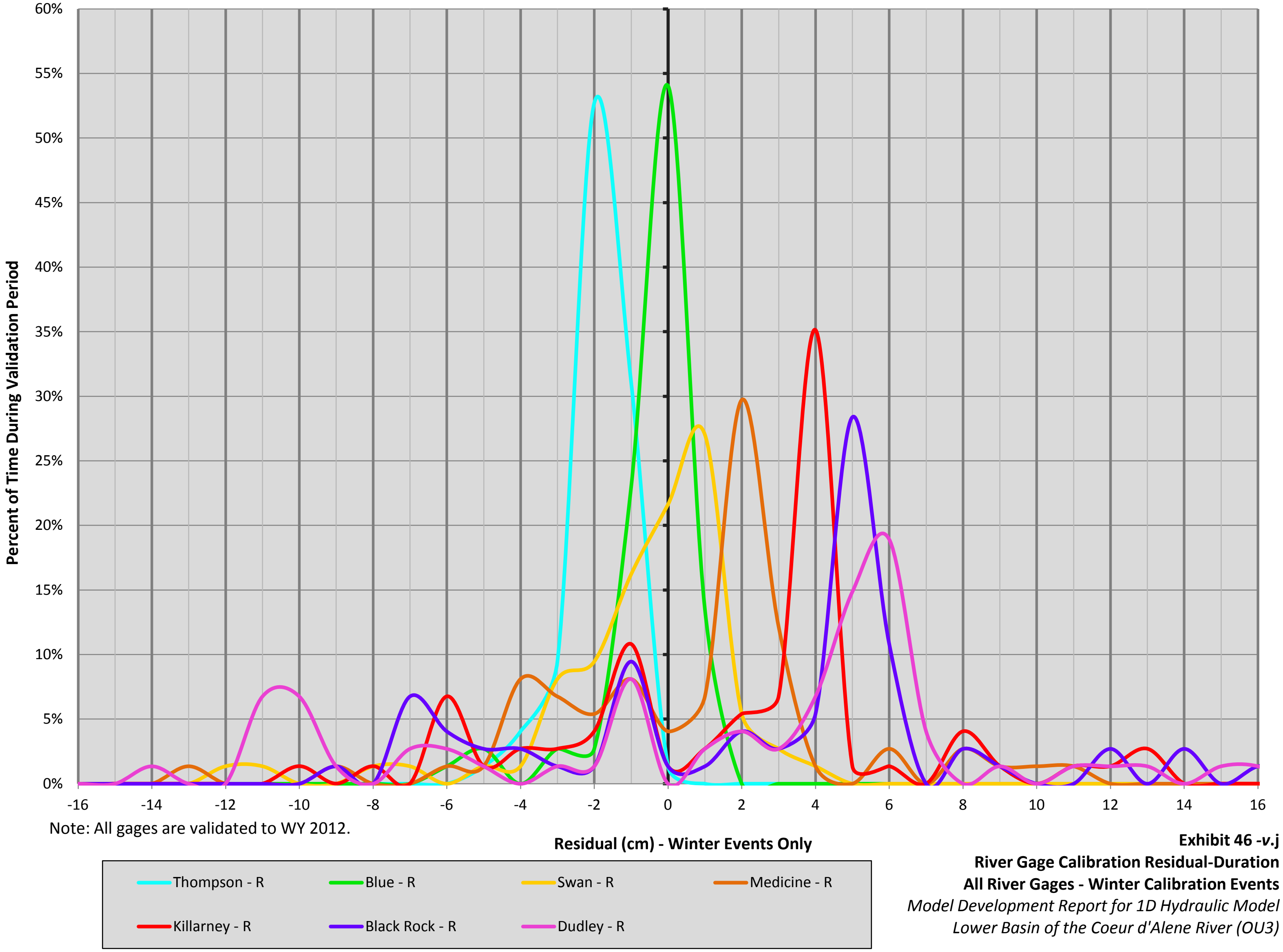
Note: All gages are validated to WY 2012.

Exhibit 46-*v*.h
River Gage Validation Residual-Duration
All River Gages - Entire Validation Period
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Note: All gages are validated to WY 2012.

Exhibit 46 -*v.* i
River Gage Validation Residual-Duration
All River Gages - Spring Calibration Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Note: All gages are validated to WY 2012.

Exhibit 46 -*v*.j
River Gage Calibration Residual-Duration
All River Gages - Winter Calibration Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

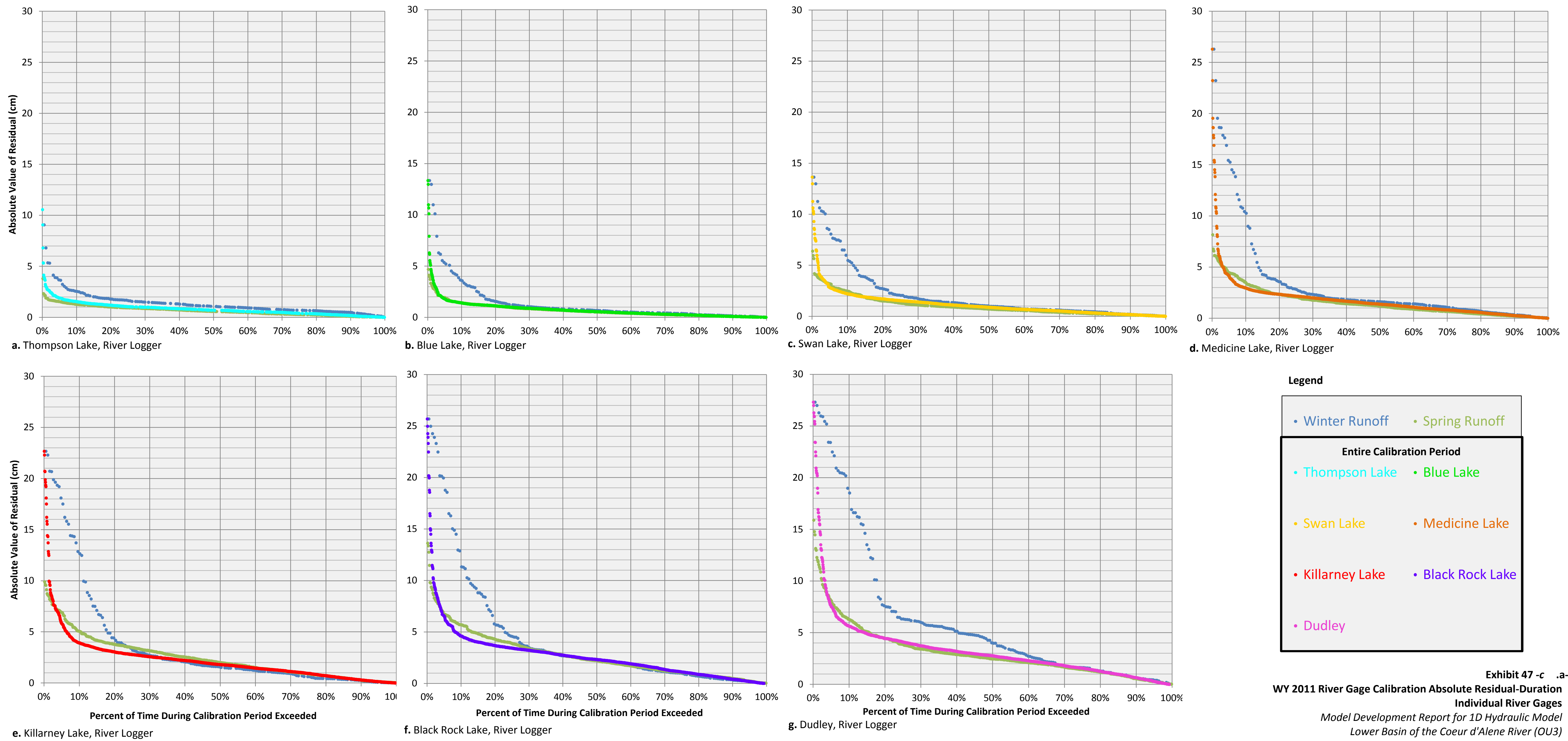


Exhibit 47 -c .a-g
WY 2011 River Gage Calibration Absolute Residual-Duration
Individual River Gages
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

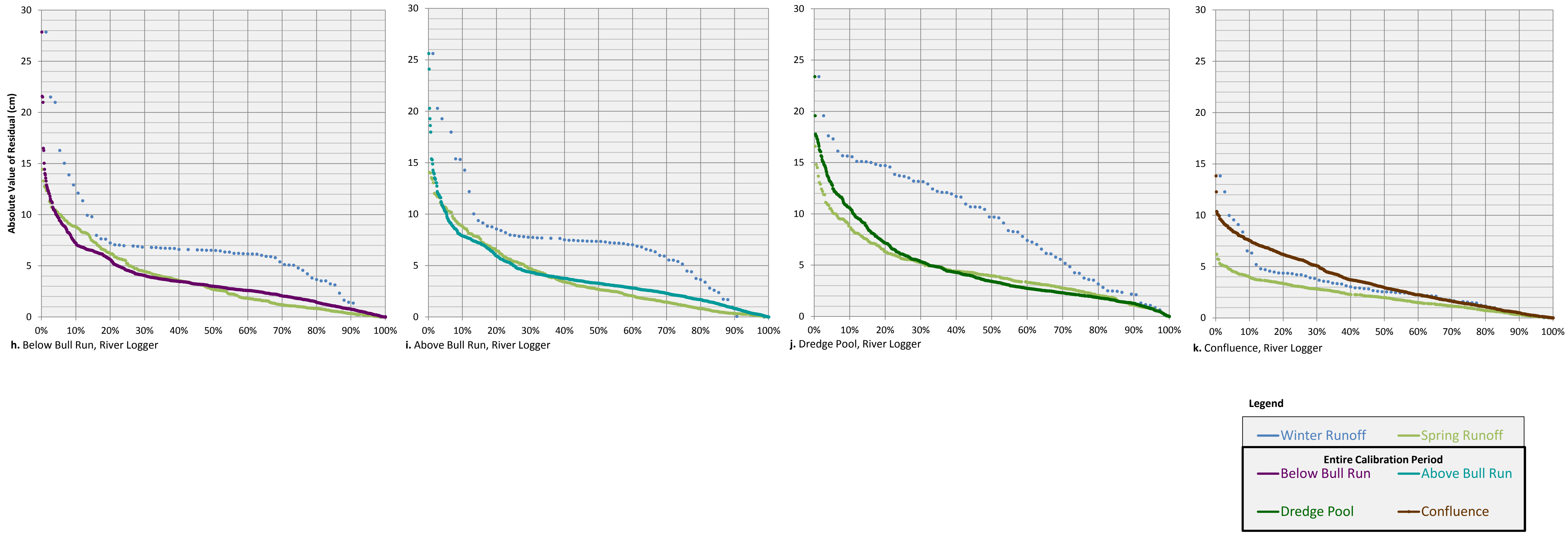


Exhibit 47 -c . h-k

WY 2012 River Gage Calibration Absolute Residual-Duration

Individual River Gages

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3

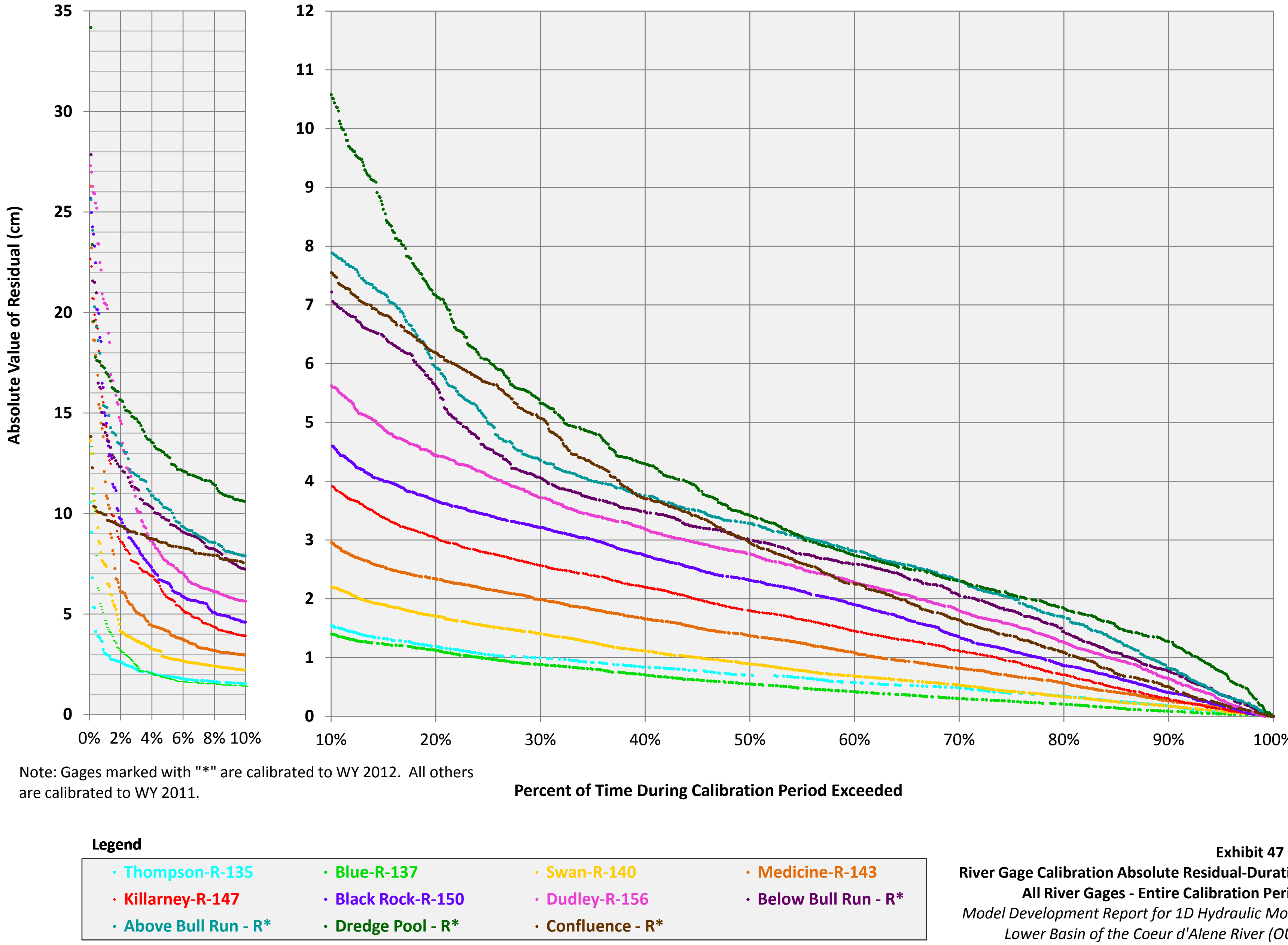


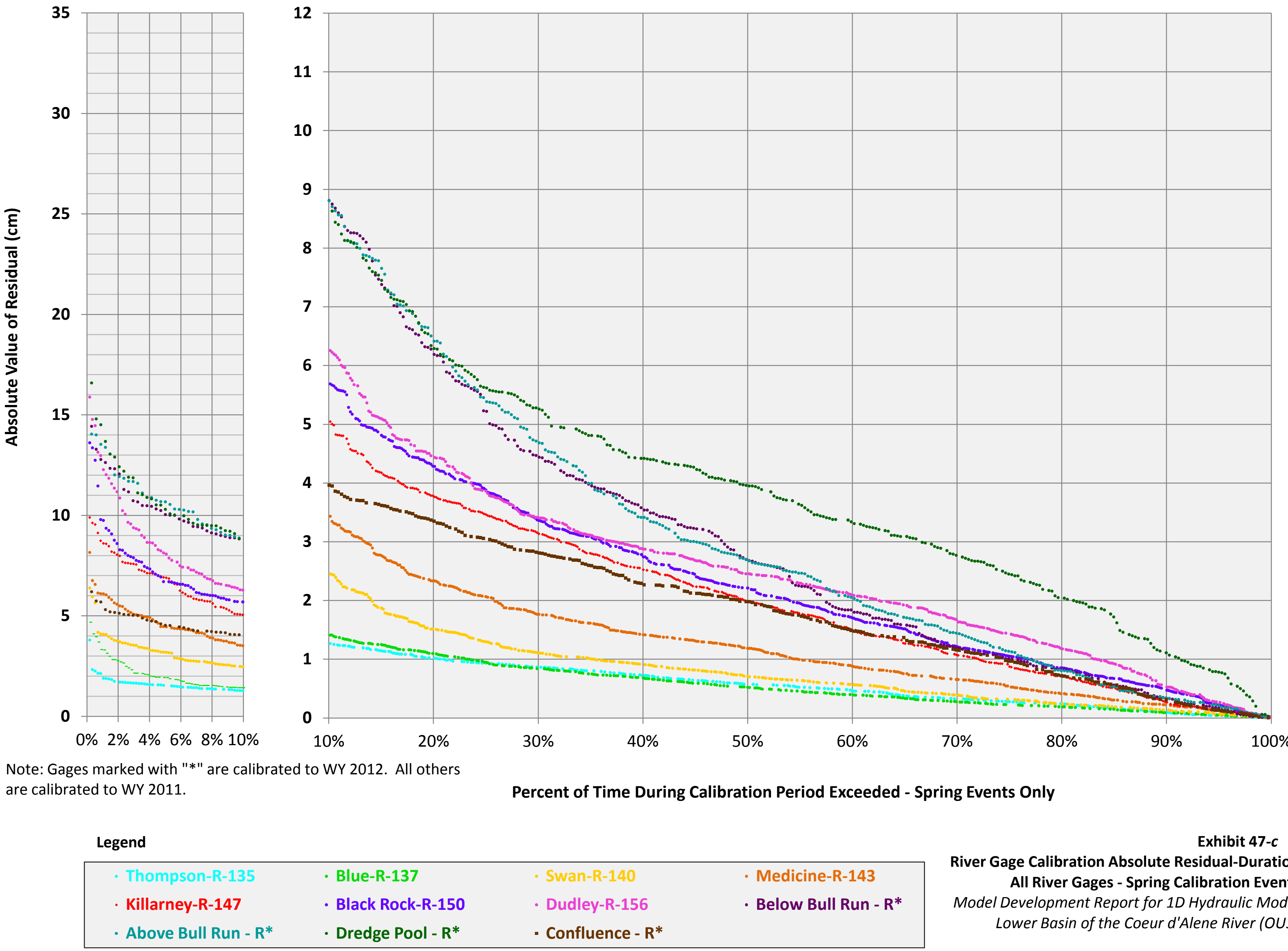
Exhibit 47 -c .l

River Gage Calibration Absolute Residual-Duration

All River Gages - Entire Calibration Period

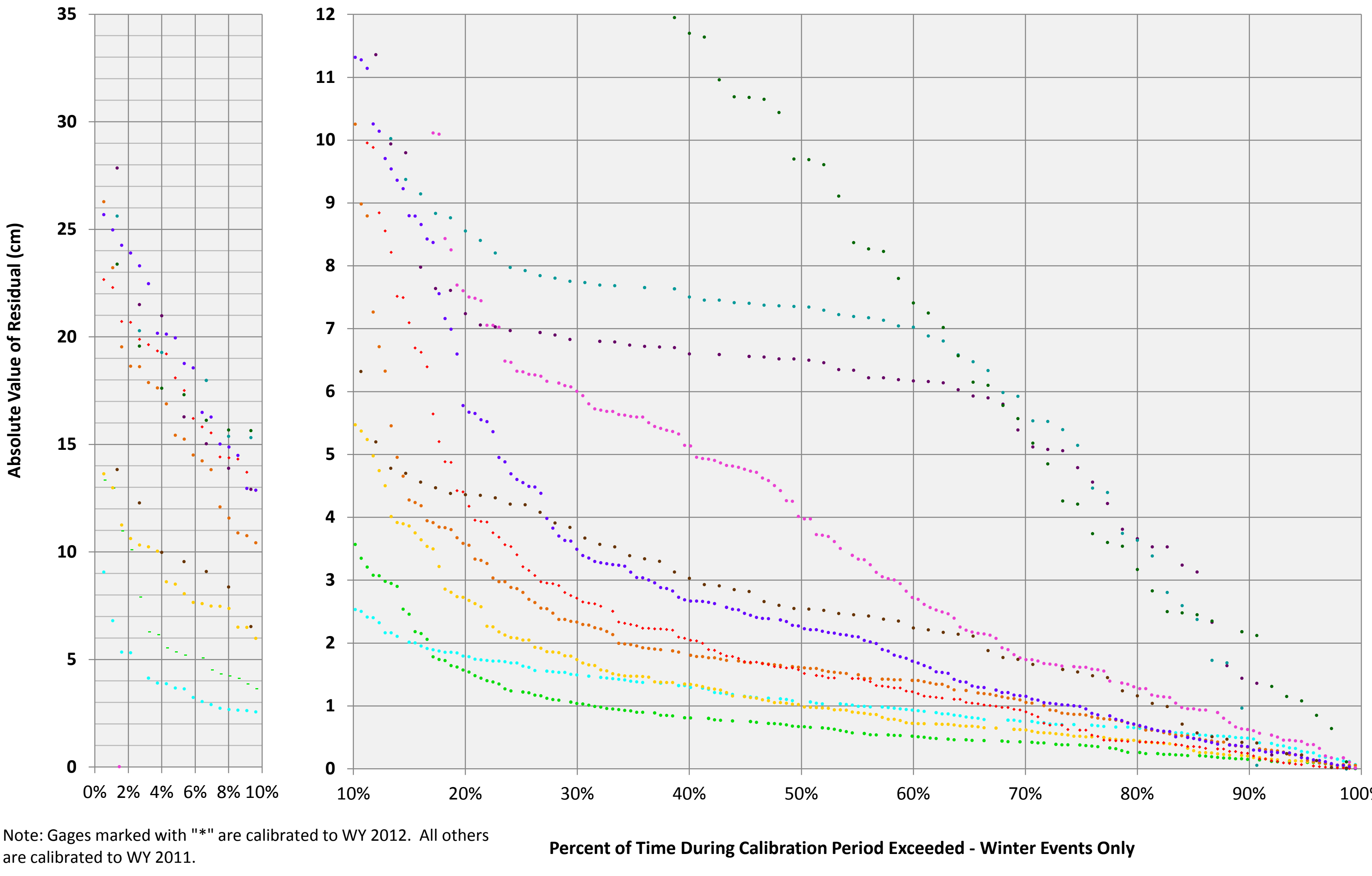
Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)



Note: Gages marked with "*" are calibrated to WY 2012. All others are calibrated to WY 2011.

Exhibit 47-*c* .m
River Gage Calibration Absolute Residual-Duration
All River Gages - Spring Calibration Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Note: Gages marked with "*" are calibrated to WY 2012. All others are calibrated to WY 2011.

Percent of Time During Calibration Period Exceeded - Winter Events Only

Exhibit 47 -c .n

River Gage Calibration Absolute Residual-Duration

All River Gages - Winter Calibration Events

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

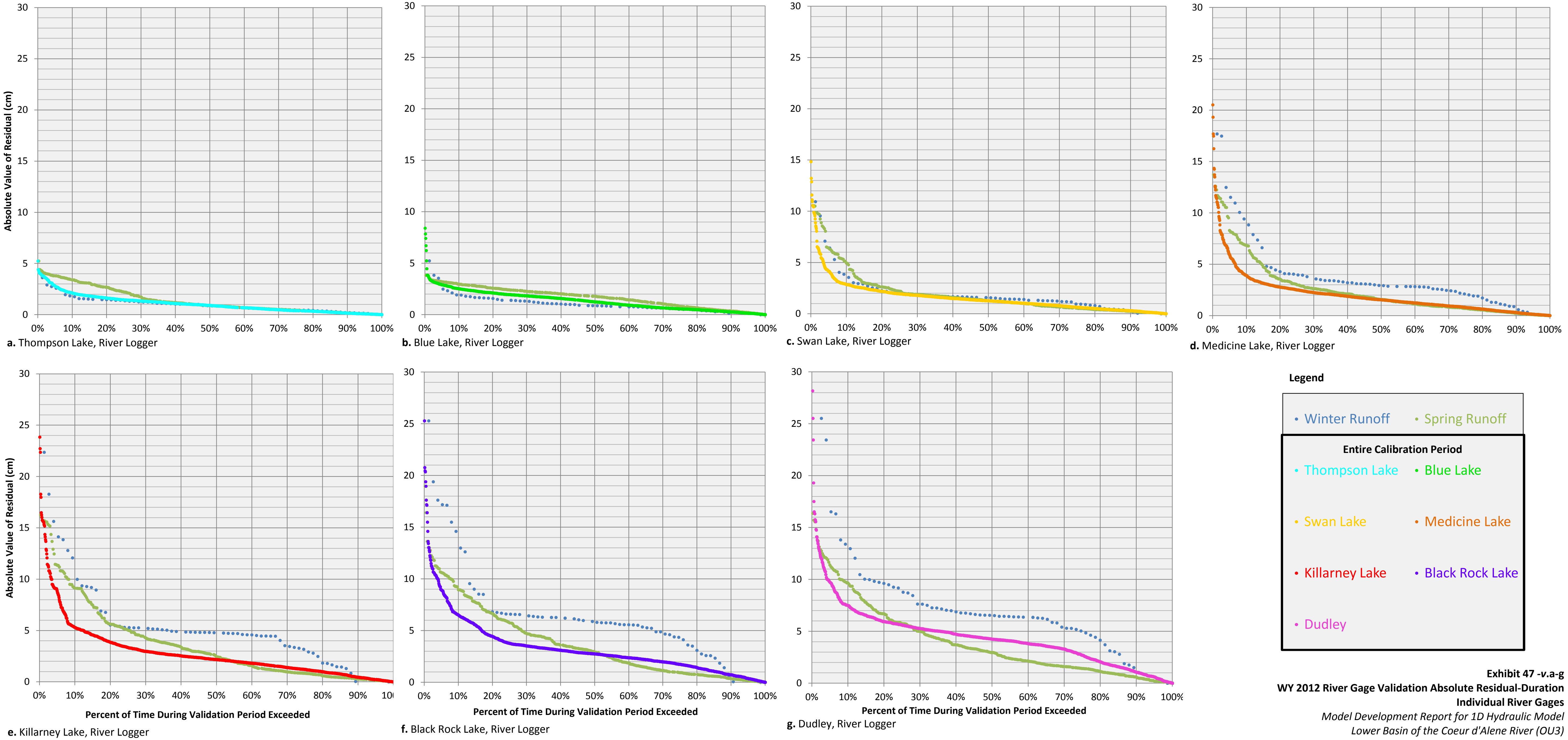


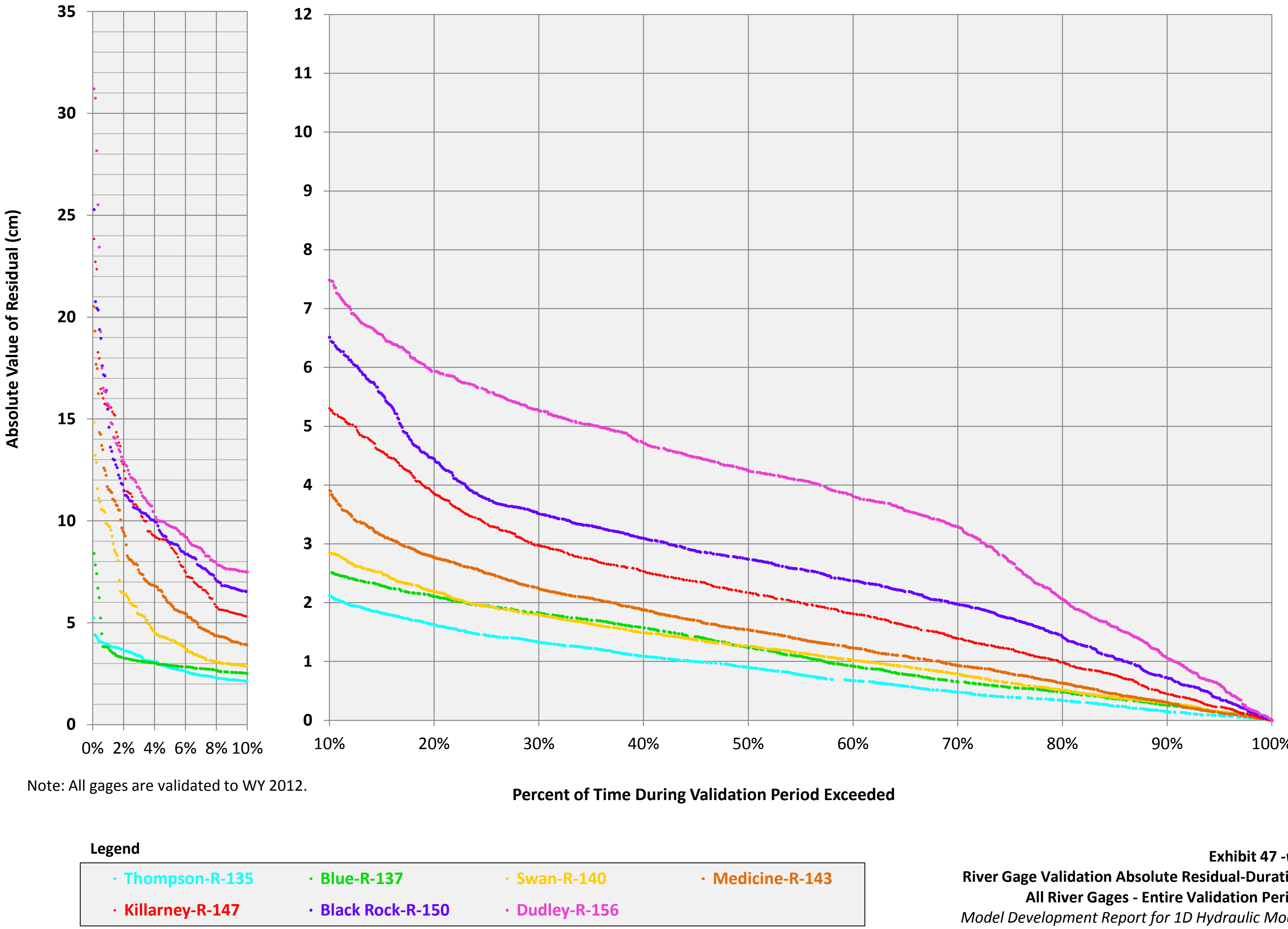
Exhibit 47 -v.a-g

WY 2012 River Gage Validation Absolute Residual-Duration

Individual River Gages

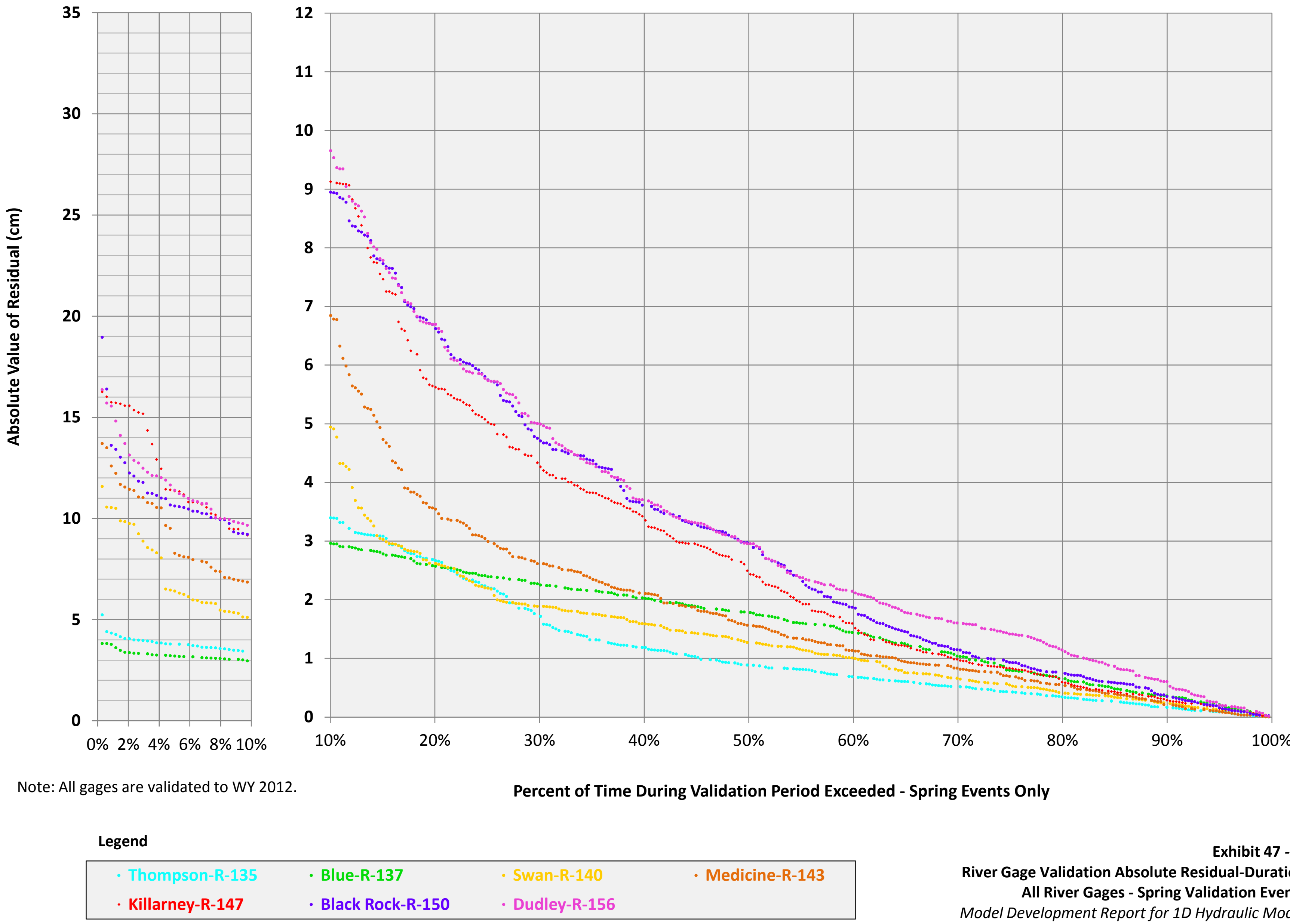
Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)



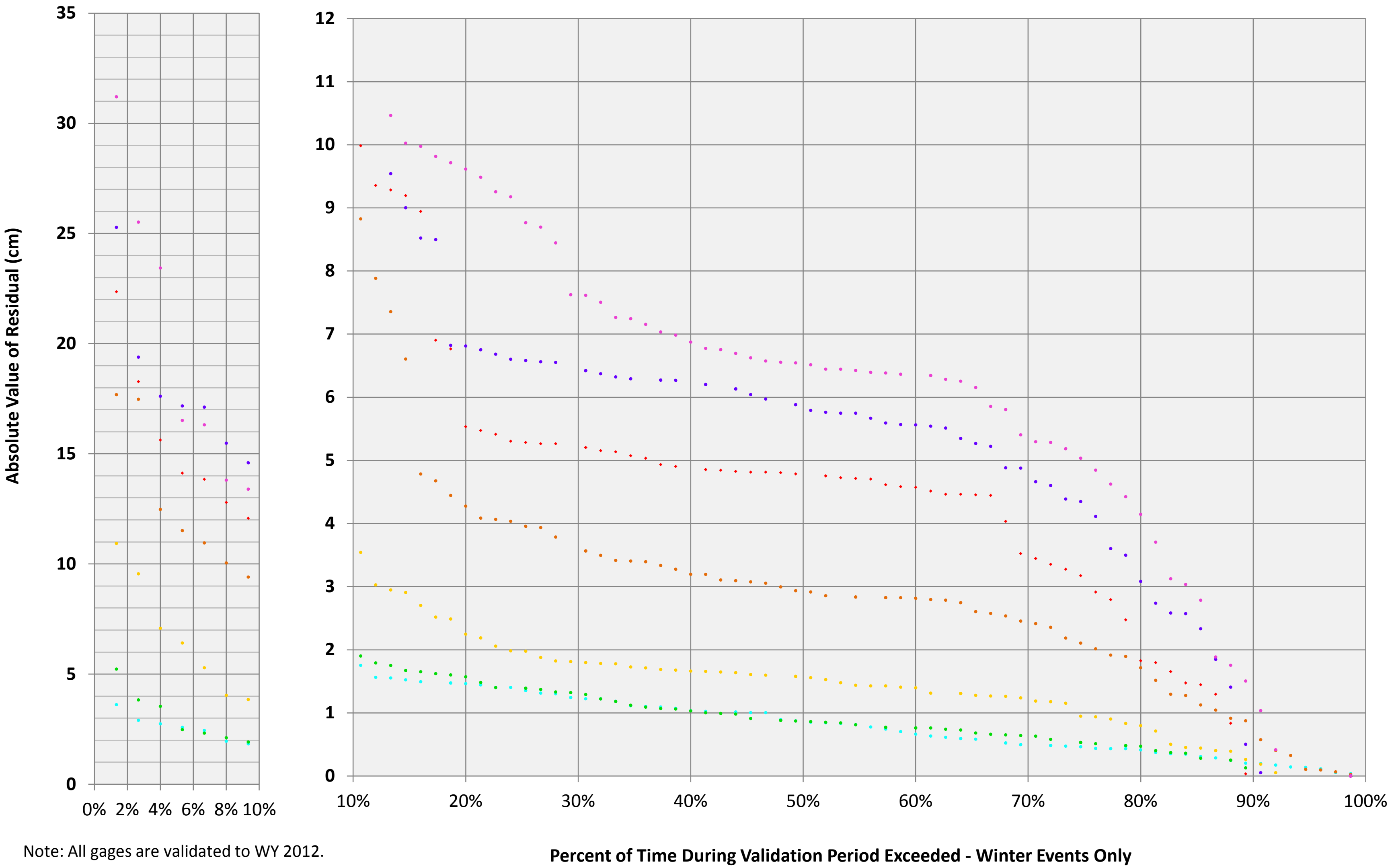
Note: All gages are validated to WY 2012.

Exhibit 47 -*v*.h
River Gage Validation Absolute Residual-Duration
All River Gages - Entire Validation Period
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Note: All gages are validated to WY 2012.

Exhibit 47 -*v*.i
River Gage Validation Absolute Residual-Duration
All River Gages - Spring Validation Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



Note: All gages are validated to WY 2012.

Legend

Thompson-R-135	Blue-R-137	Swan-R-140	Medicine-R-143
Killarney-R-147	Black Rock-R-150	Dudley-R-156	

Exhibit 47 -v.j
River Gage Validation Absolute Residual-Duration
All River Gages - Winter Validation Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

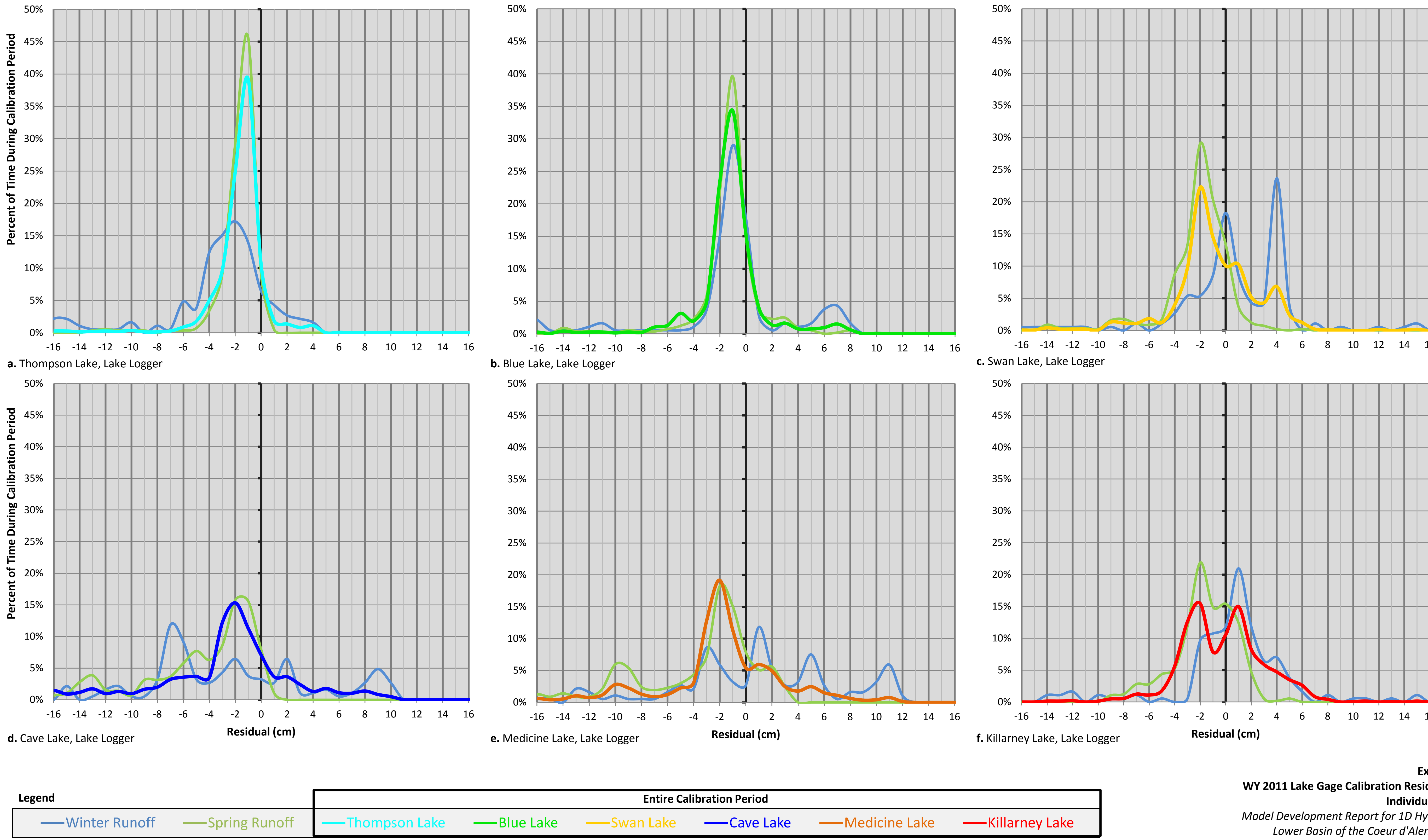


Exhibit 48 -c.a-f
WY 2011 Lake Gage Calibration Residual-Duration
Individual Lake Gages
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

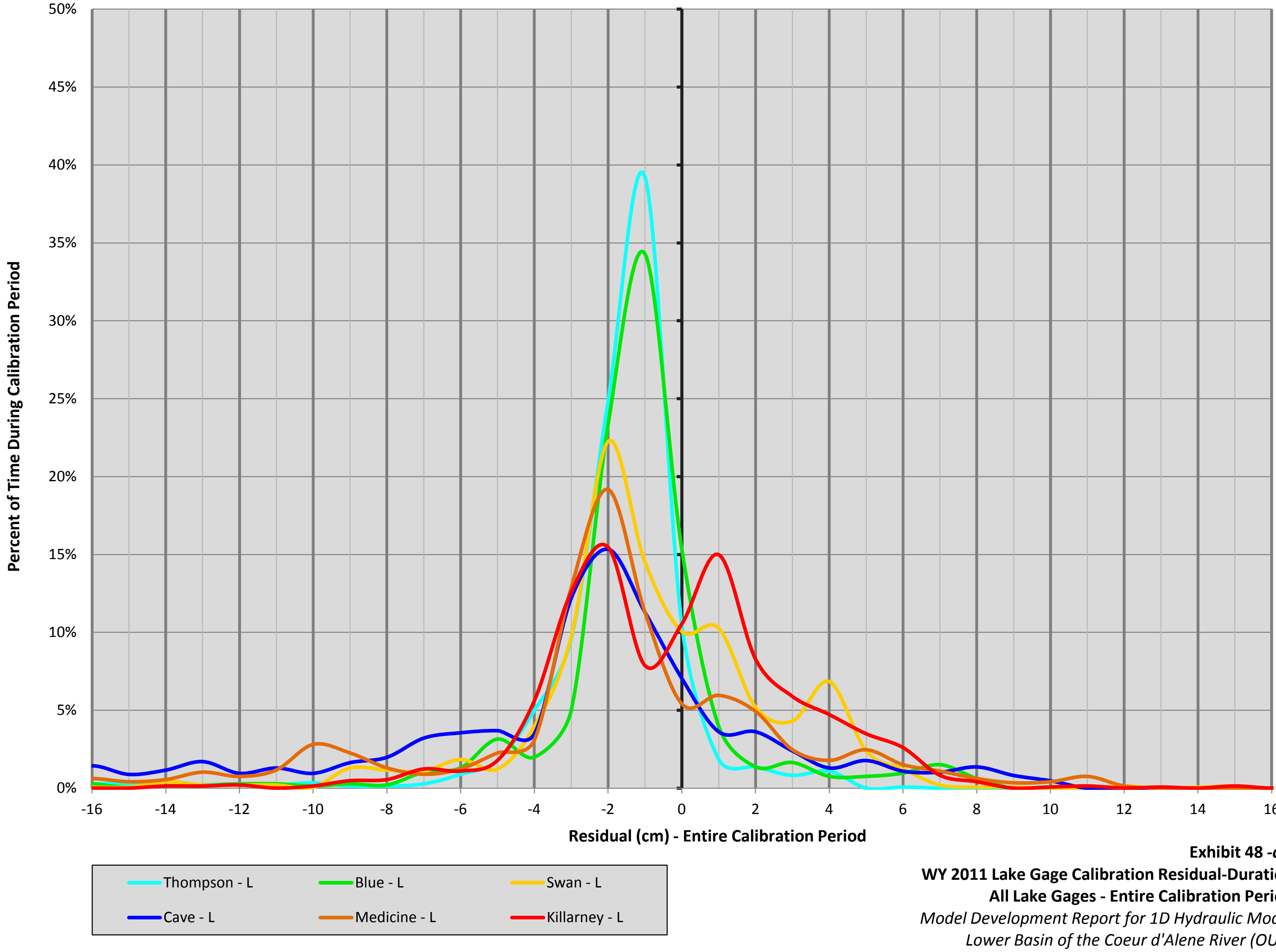


Exhibit 48 -*c.* g

WY 2011 Lake Gage Calibration Residual-Duration

All Lake Gages - Entire Calibration Period

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

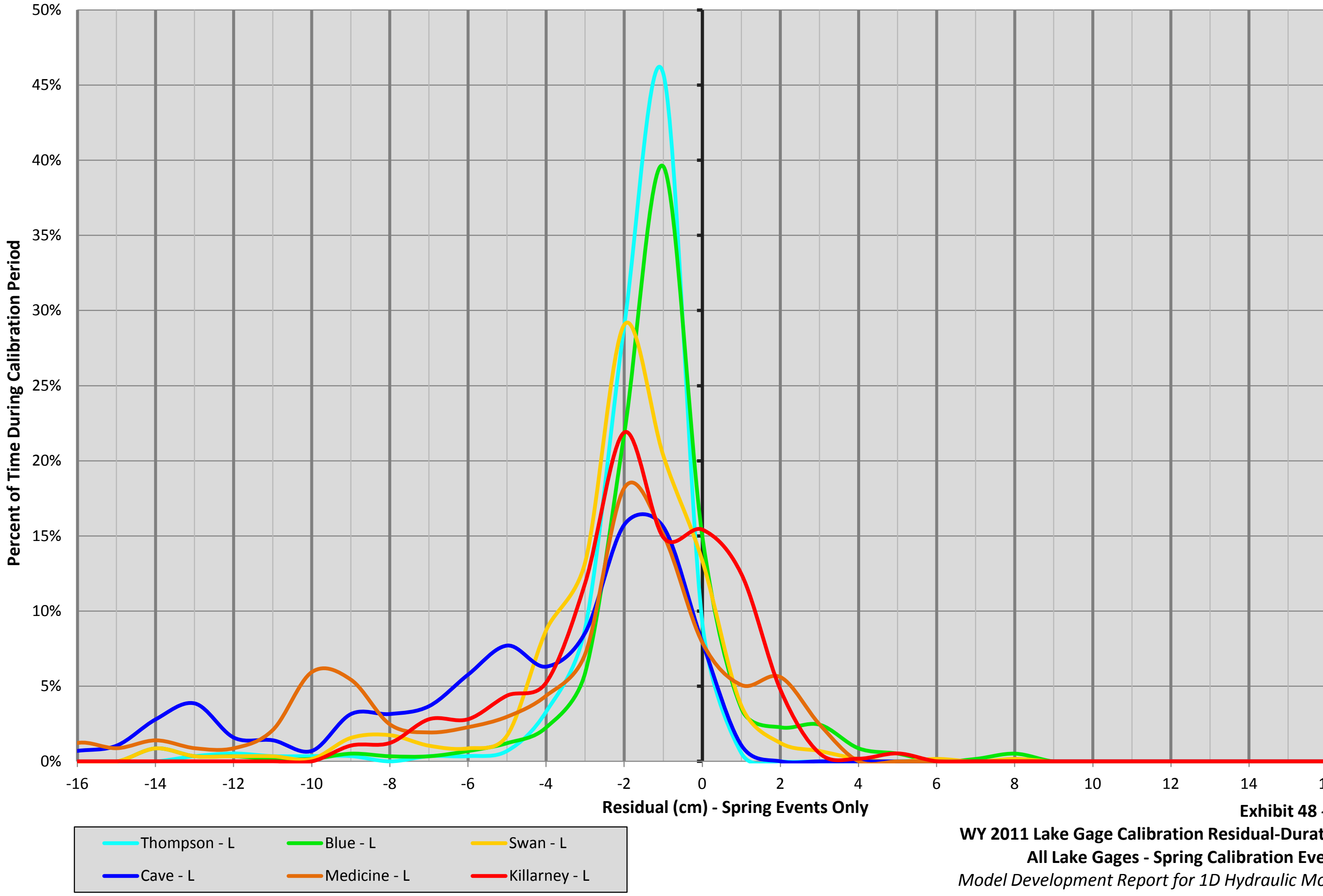


Exhibit 48 -*c.* h
WY 2011 Lake Gage Calibration Residual-Duration
All Lake Gages - Spring Calibration Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

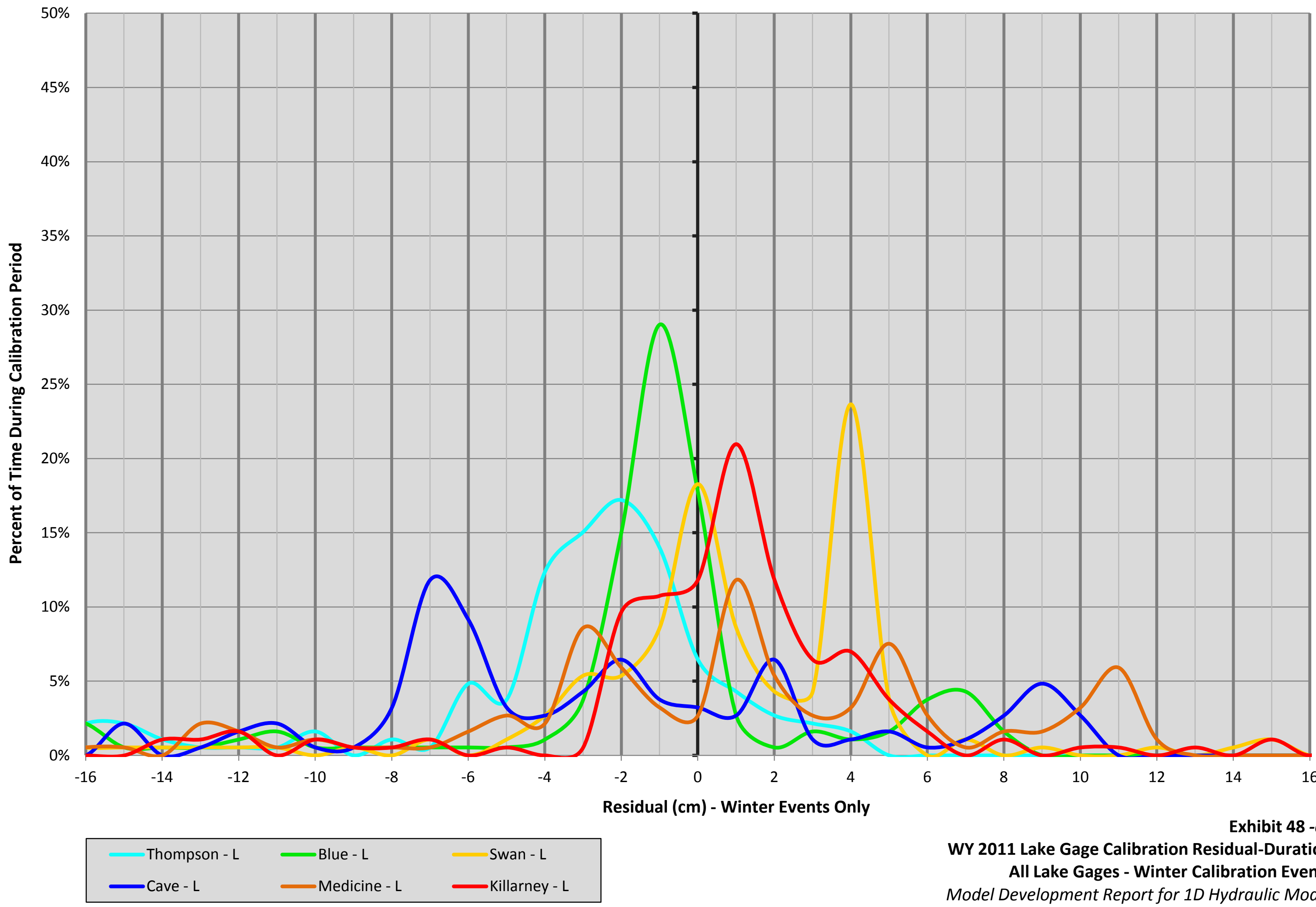


Exhibit 48 -*c.* i
WY 2011 Lake Gage Calibration Residual-Duration
All Lake Gages - Winter Calibration Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

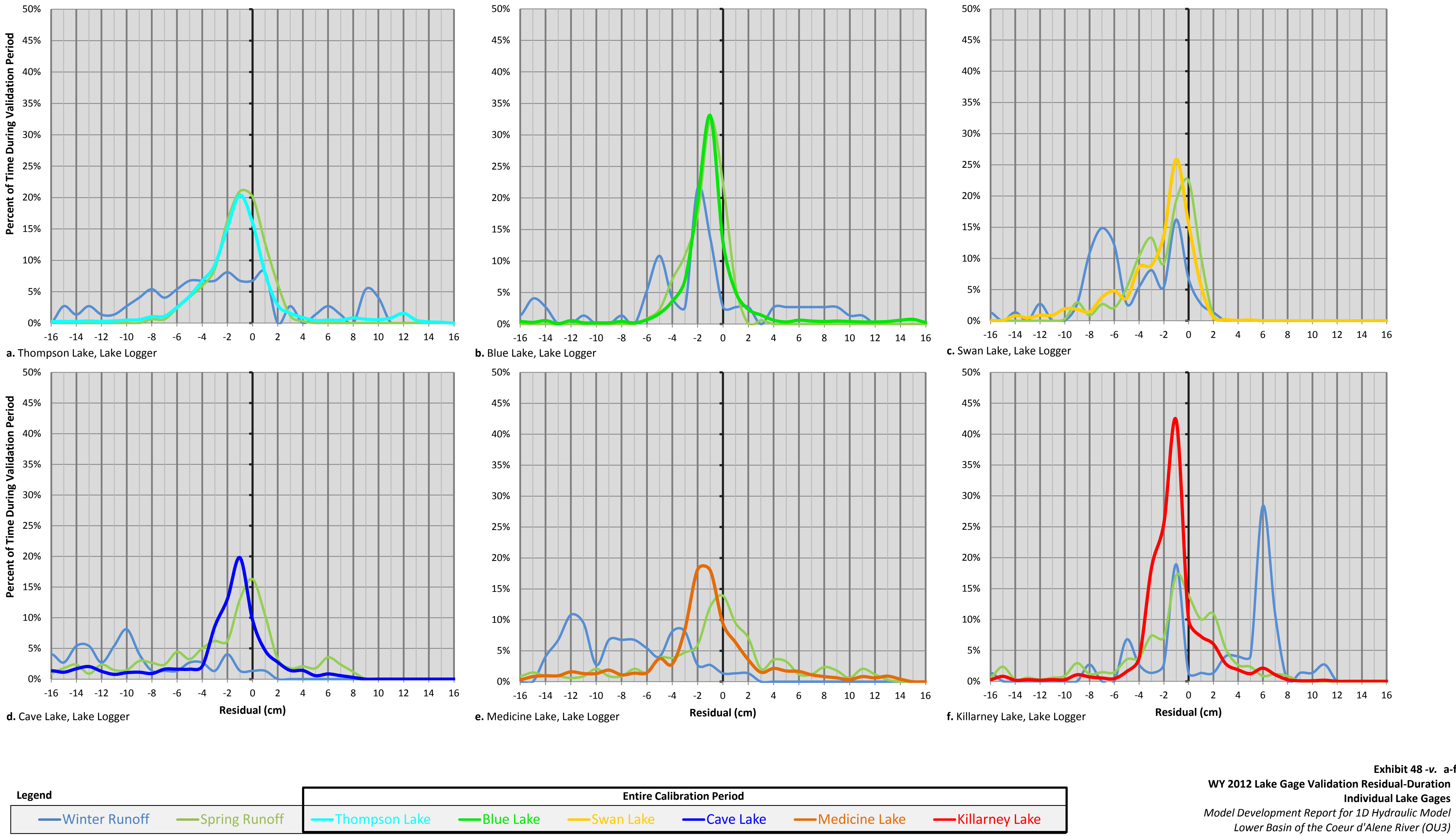


Exhibit 48 -v. a-f

WY 2012 Lake Gage Validation Residual-Duration

Individual Lake Gages

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

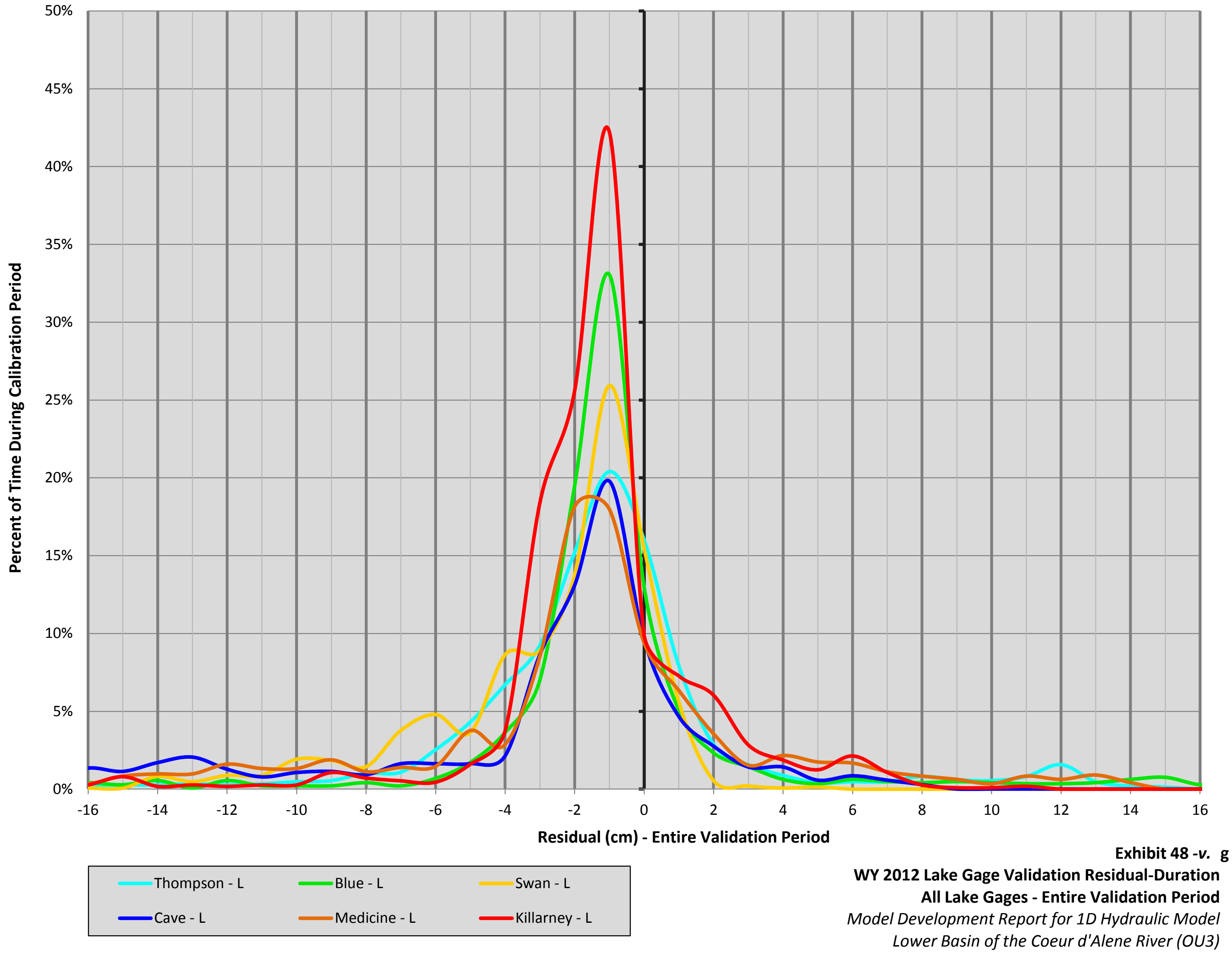


Exhibit 48 -*v.* g
WY 2012 Lake Gage Validation Residual-Duration
All Lake Gages - Entire Validation Period
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

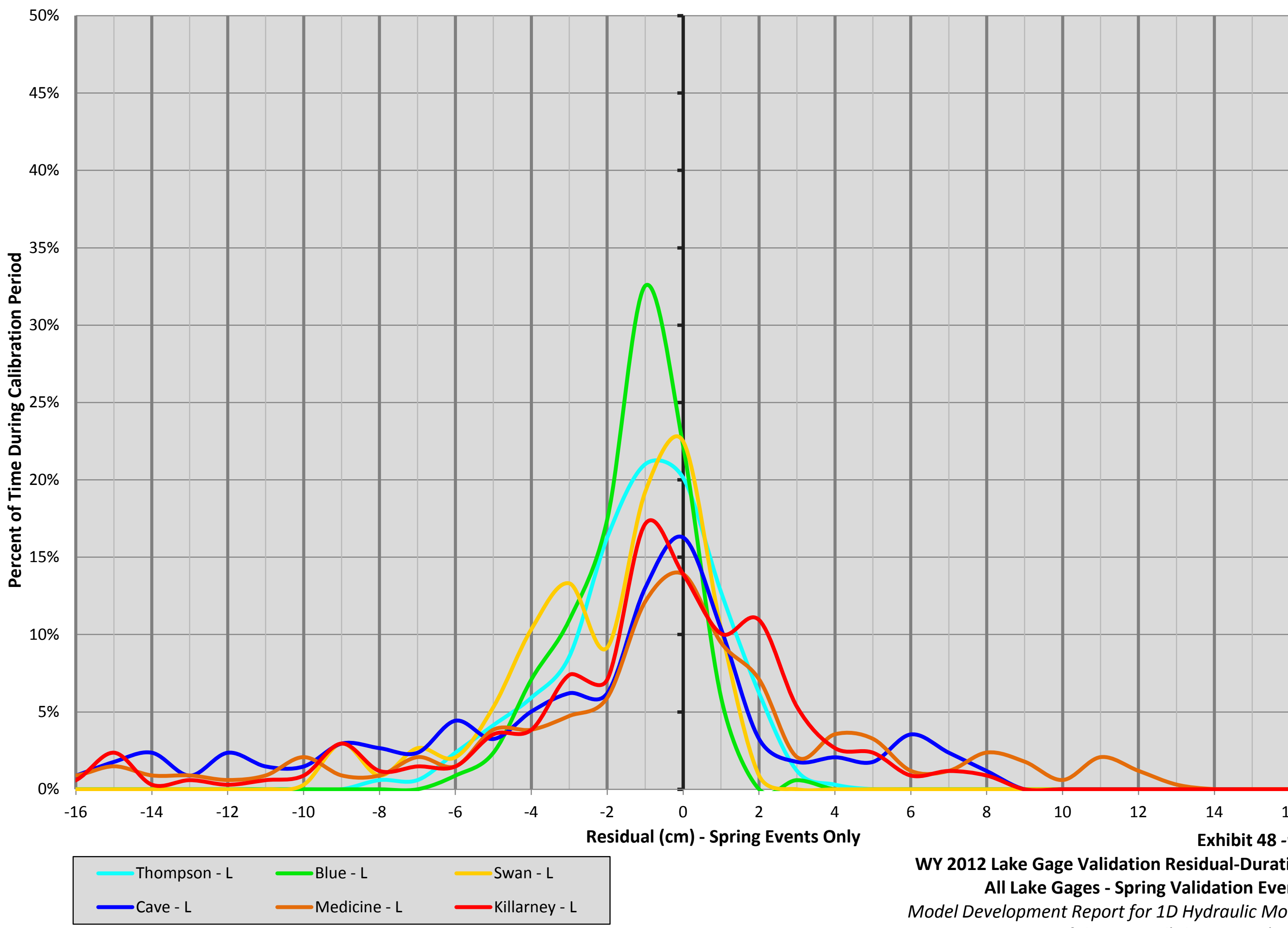


Exhibit 48 -*v.* h
WY 2012 Lake Gage Validation Residual-Duration
All Lake Gages - Spring Validation Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

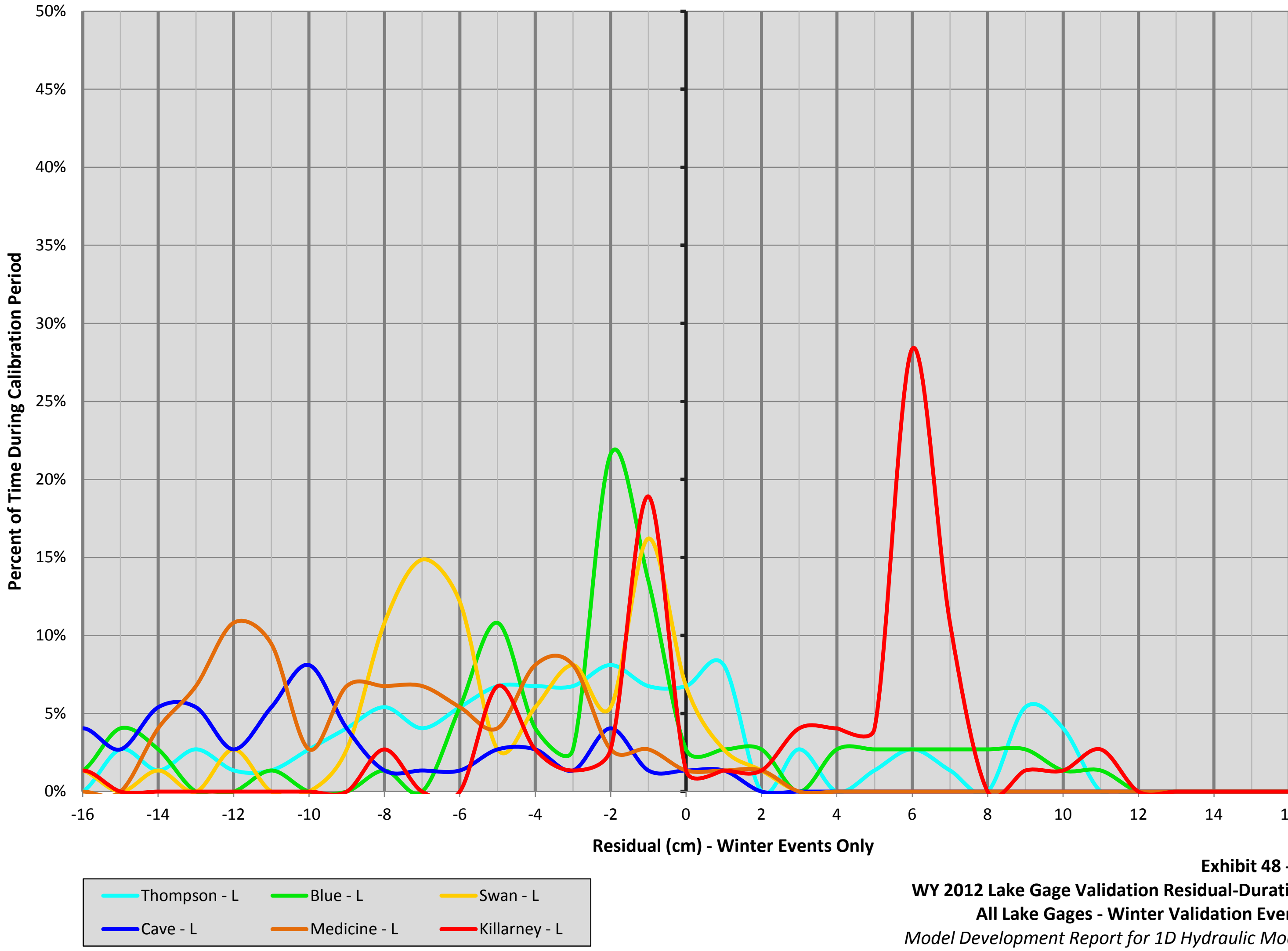
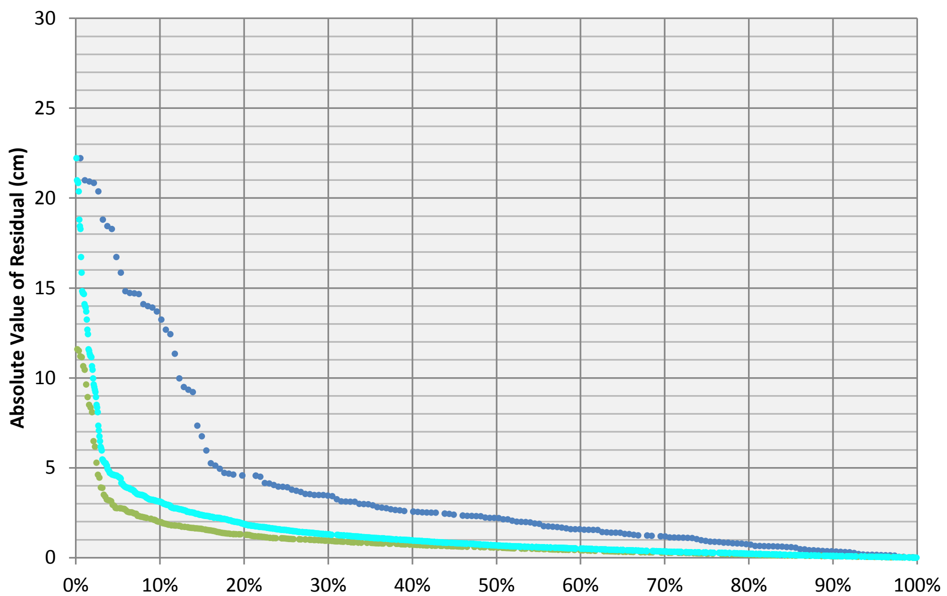
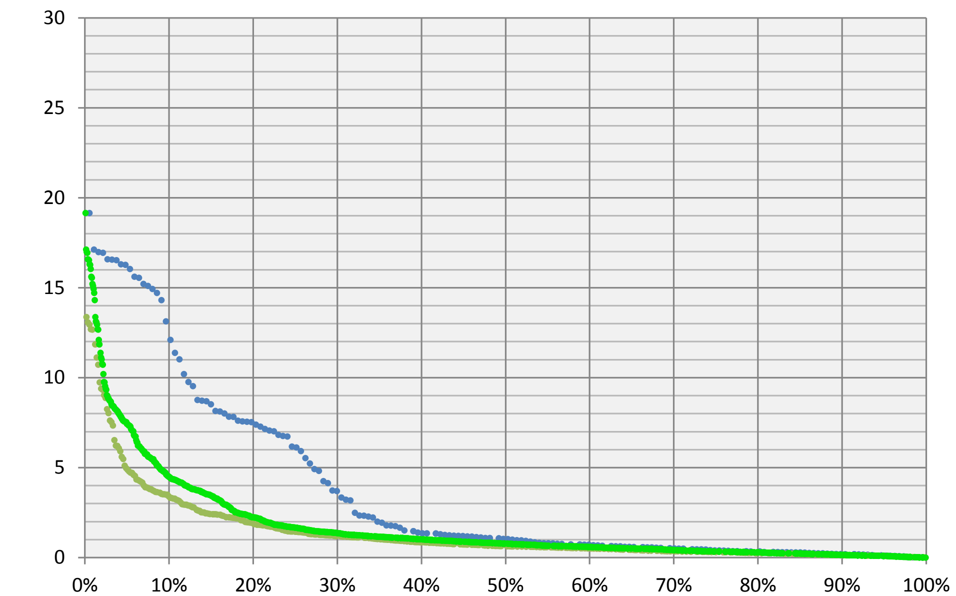


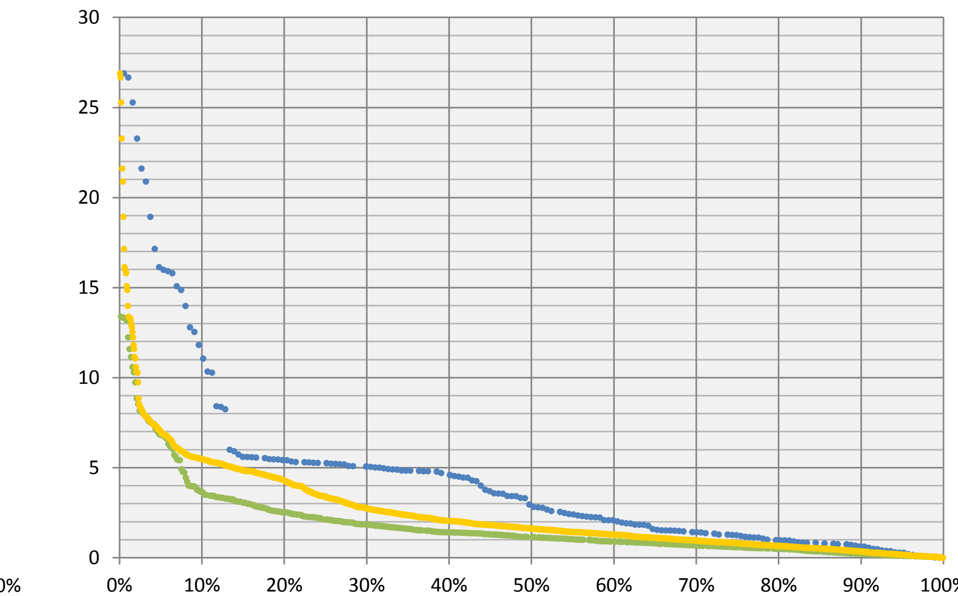
Exhibit 48 -*v.* i
WY 2012 Lake Gage Validation Residual-Duration
All Lake Gages - Winter Validation Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)



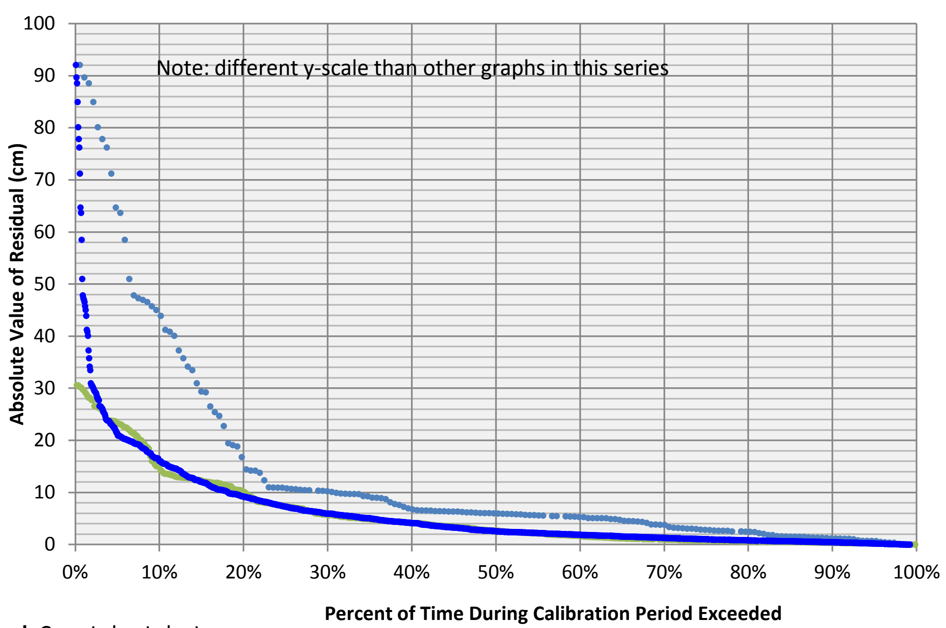
a. Thompson Lake, Lake Logger



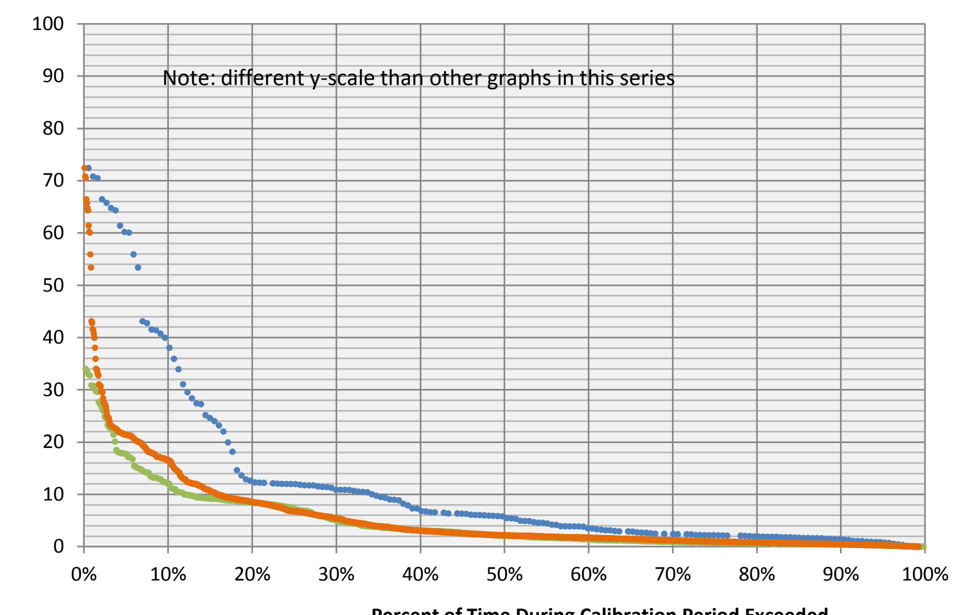
b. Blue Lake, Lake Logger



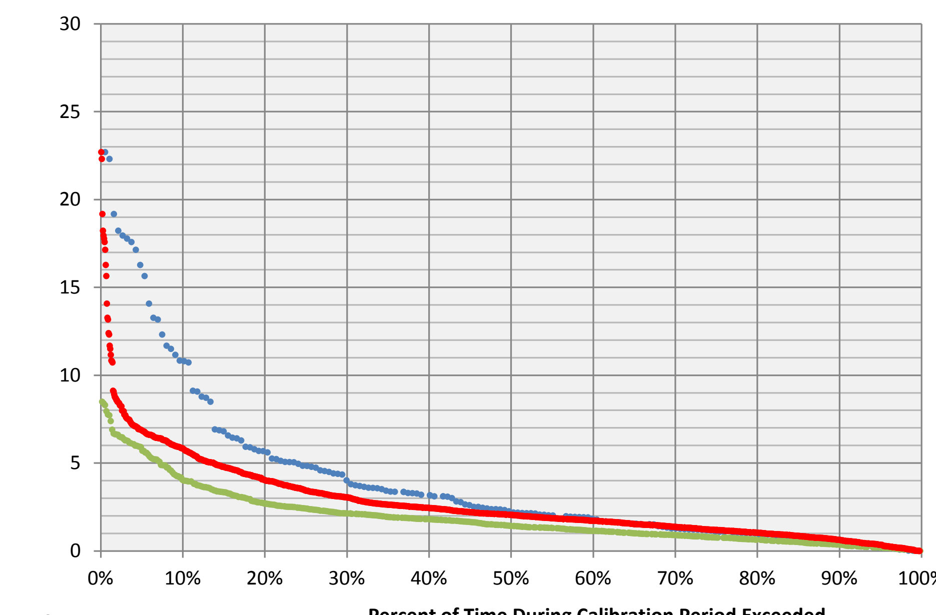
c. Swan Lake, Lake Logger



d. Cave Lake, Lake Logger



e. Medicine Lake, Lake Logger



f. Killarney Lake, Lake Logger

Legend	Entire Calibration Period		
• Winter Runoff	• Thompson Lake	• Blue Lake	• Swan Lake
• Spring Runoff	• Cave Lake	• Medicine Lake	• Killarney Lake

Exhibit 49 -*c.* a-f
WY 2011 Lake Gage Calibration Absolute Residual-Duration
Individual Lake Gages
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

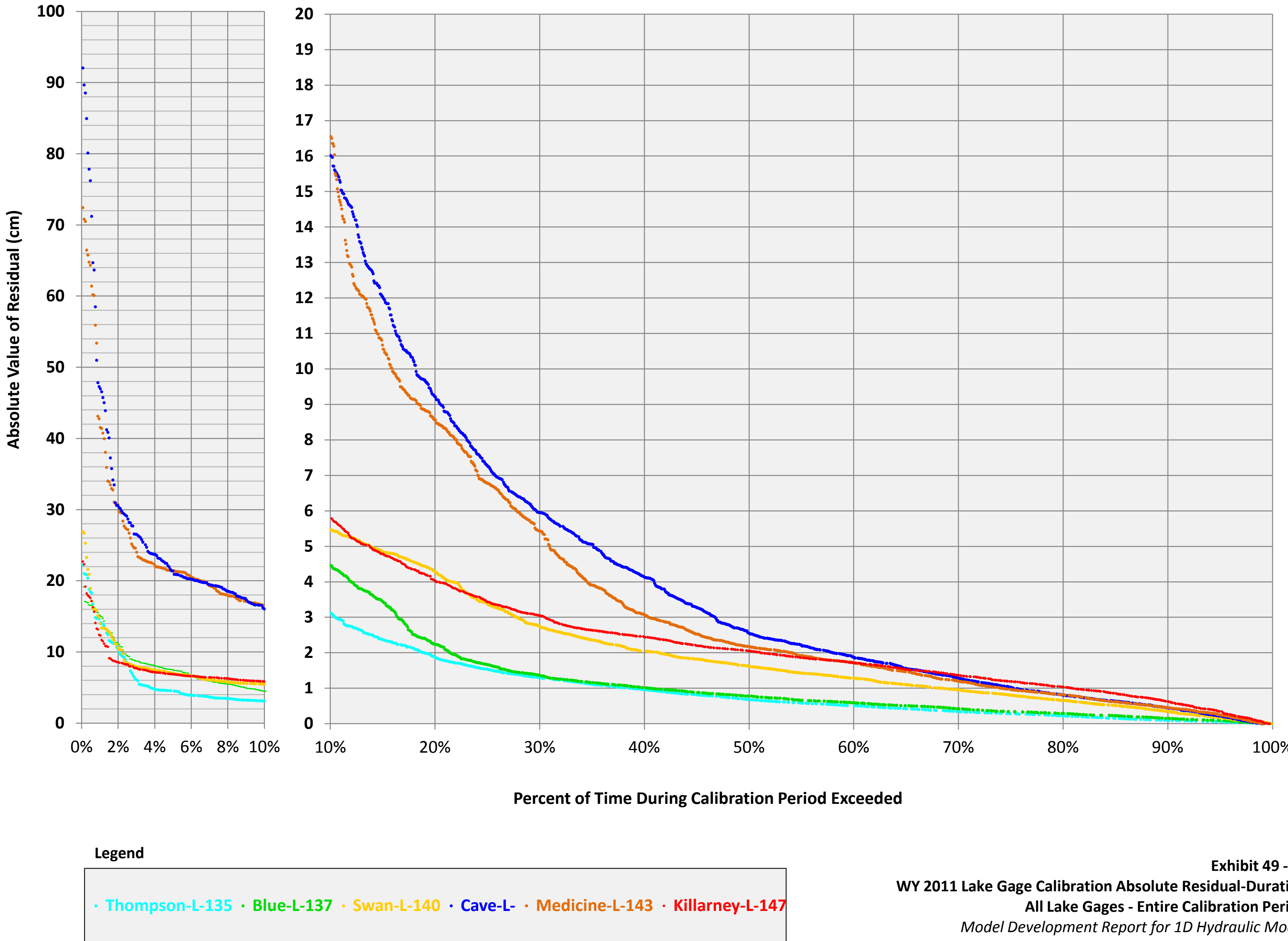


Exhibit 49 -*c.* g

WY 2011 Lake Gage Calibration Absolute Residual-Duration

All Lake Gages - Entire Calibration Period

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

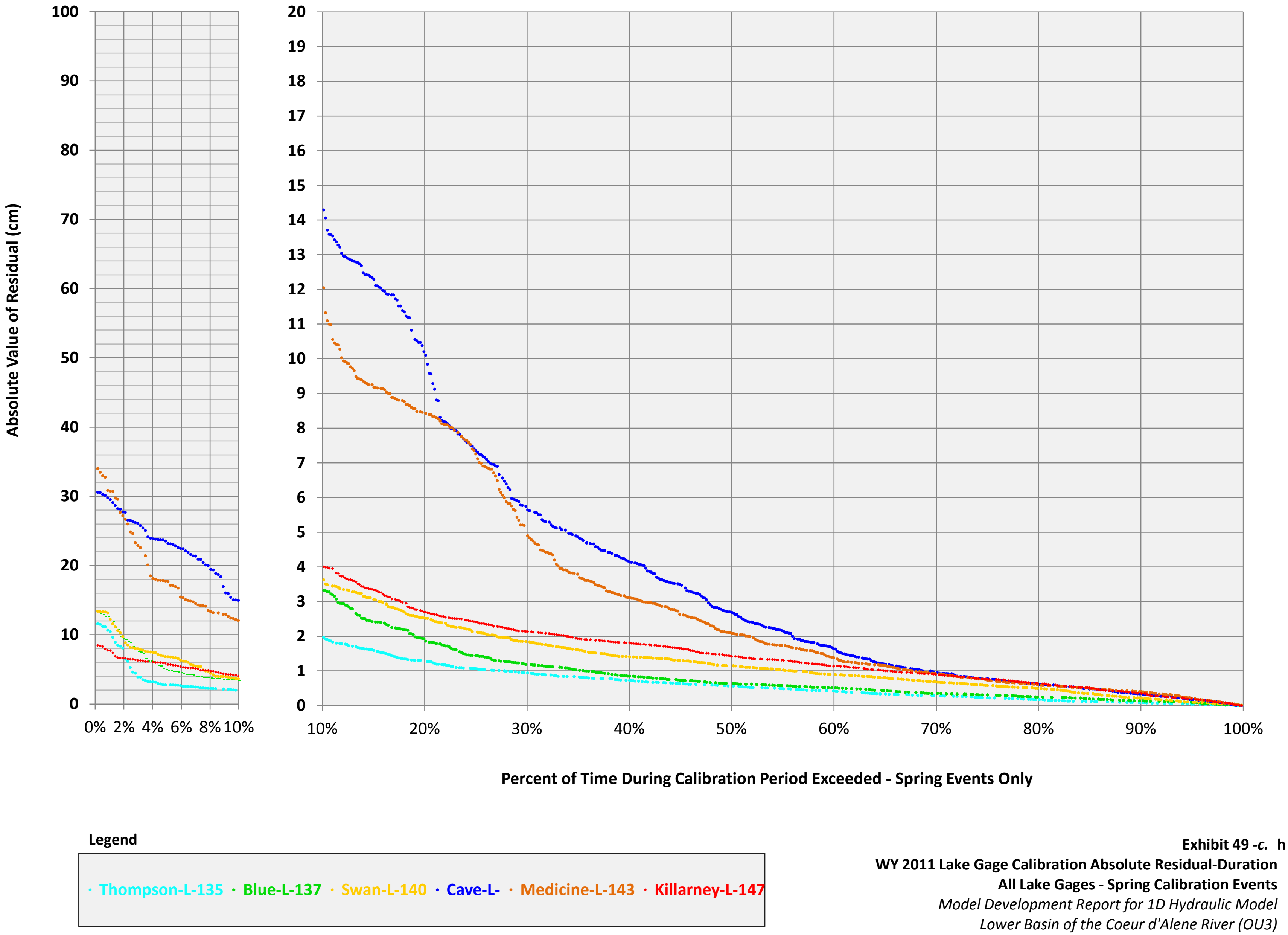


Exhibit 49 -*c.* h

WY 2011 Lake Gage Calibration Absolute Residual-Duration

All Lake Gages - Spring Calibration Events

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

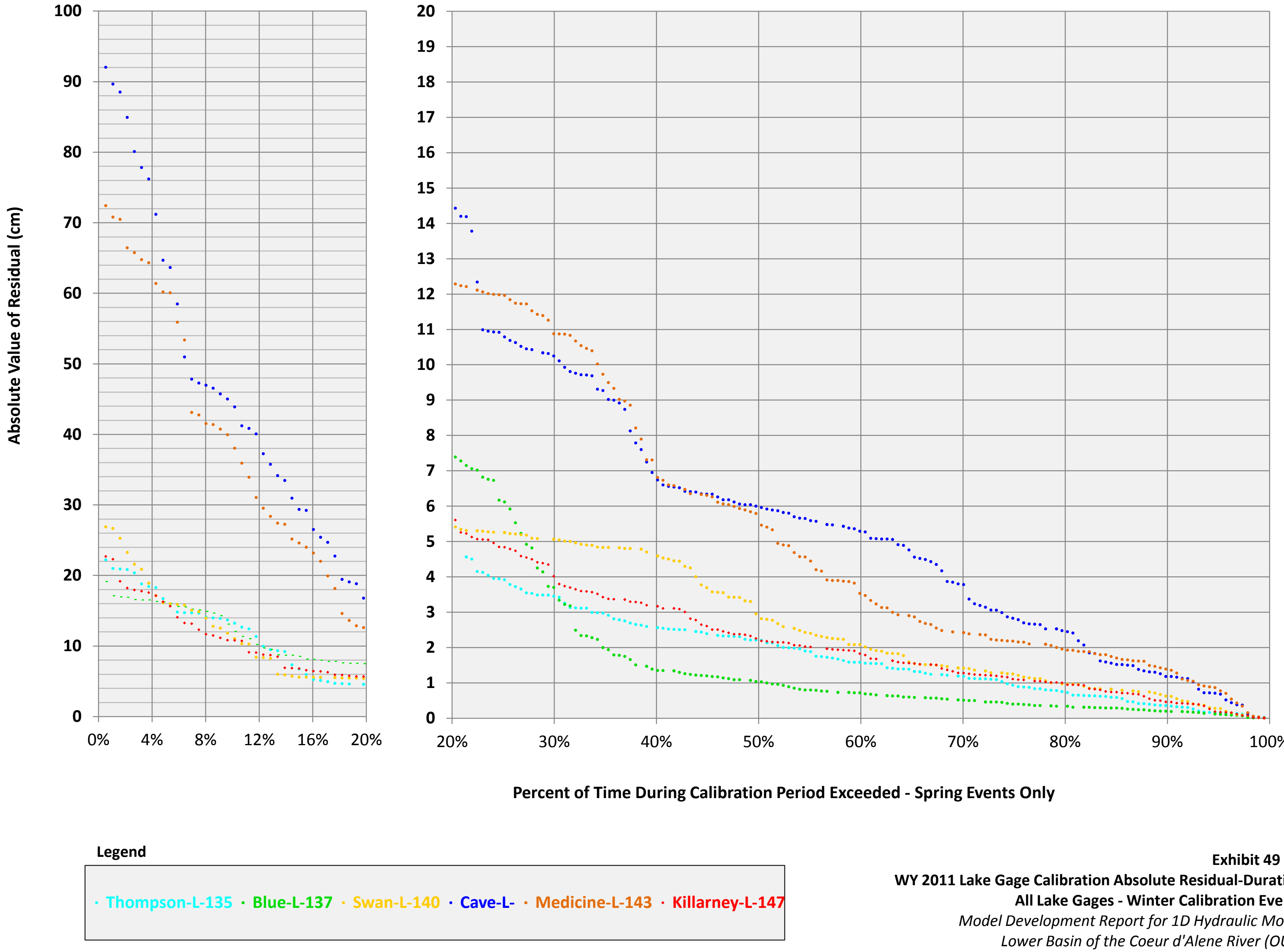


Exhibit 49 -*c.* i
WY 2011 Lake Gage Calibration Absolute Residual-Duration
All Lake Gages - Winter Calibration Events
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

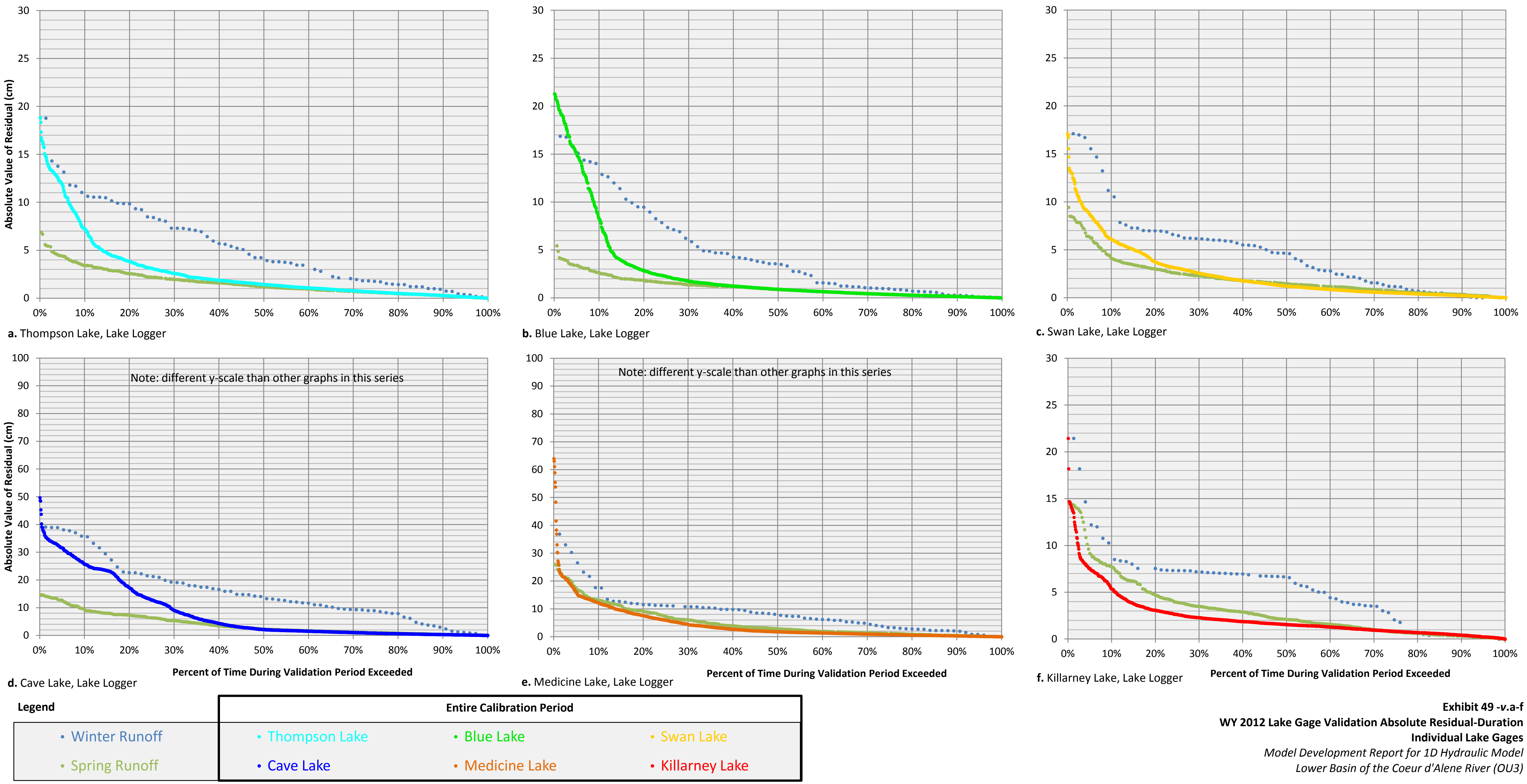


Exhibit 49 -v.a-f
WY 2012 Lake Gage Validation Absolute Residual-Duration
Individual Lake Gages
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

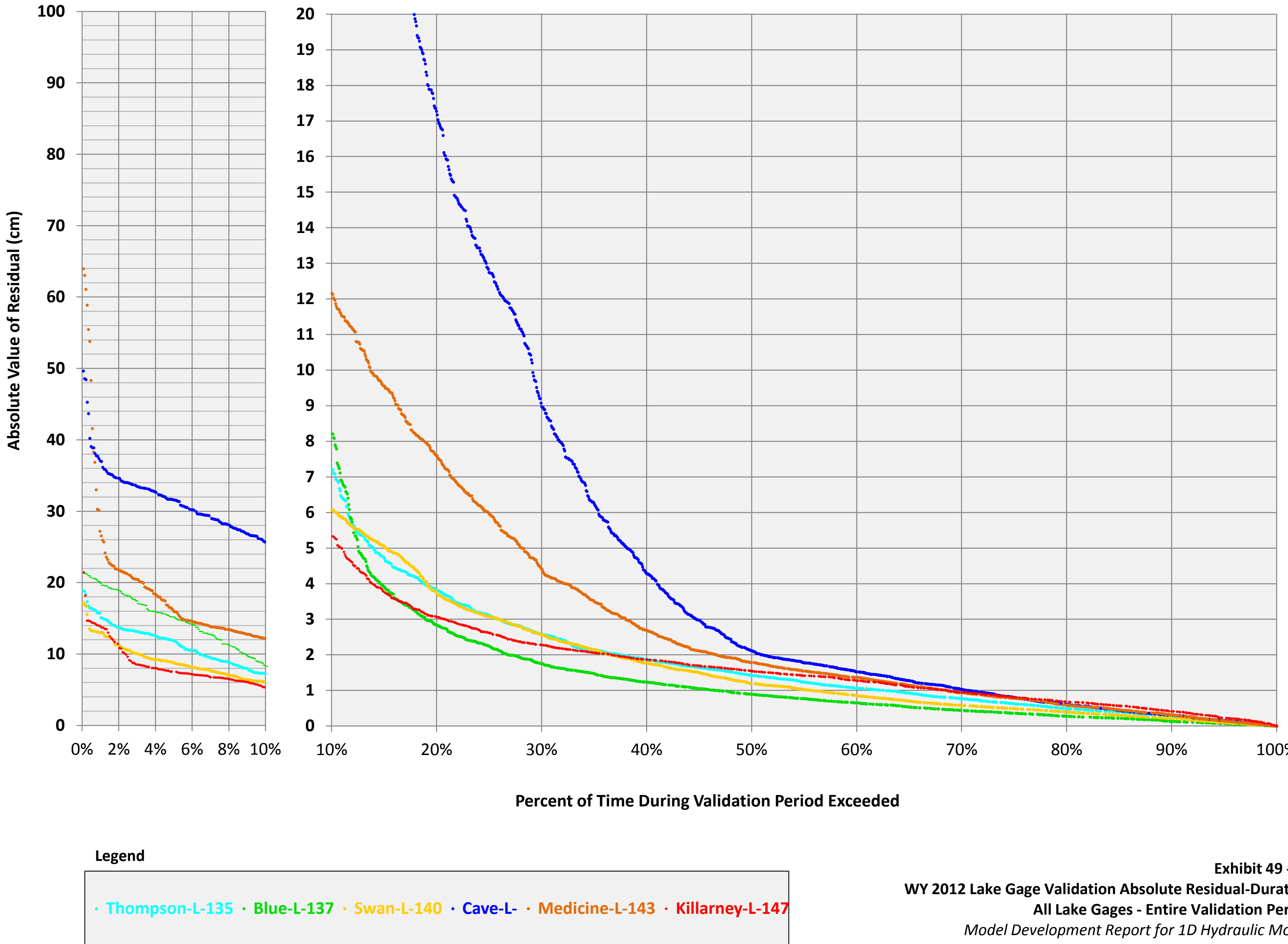


Exhibit 49 -v. g

WY 2012 Lake Gage Validation Absolute Residual-Duration

All Lake Gages - Entire Validation Period

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

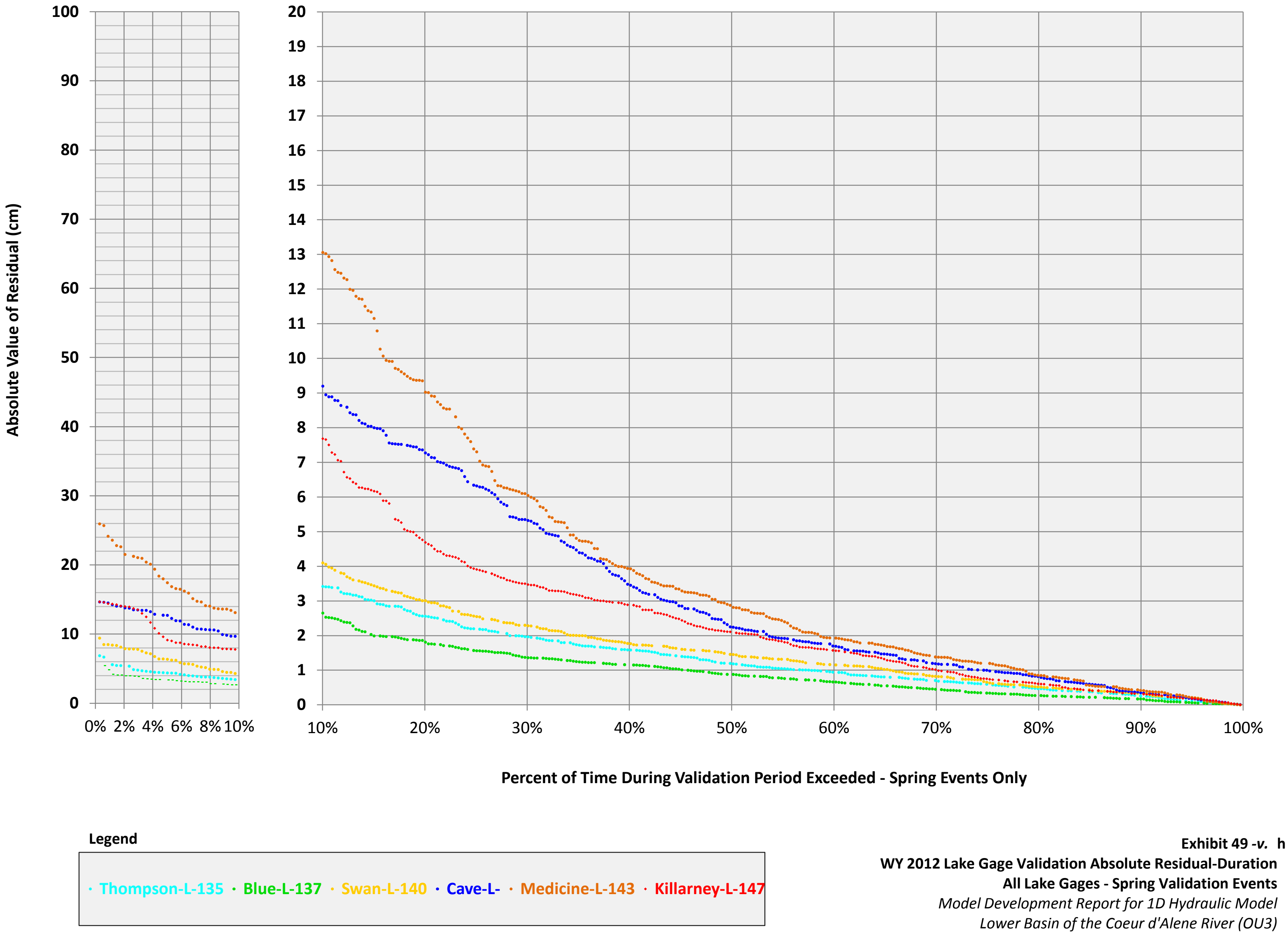


Exhibit 49 -v. h

WY 2012 Lake Gage Validation Absolute Residual-Duration

All Lake Gages - Spring Validation Events

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

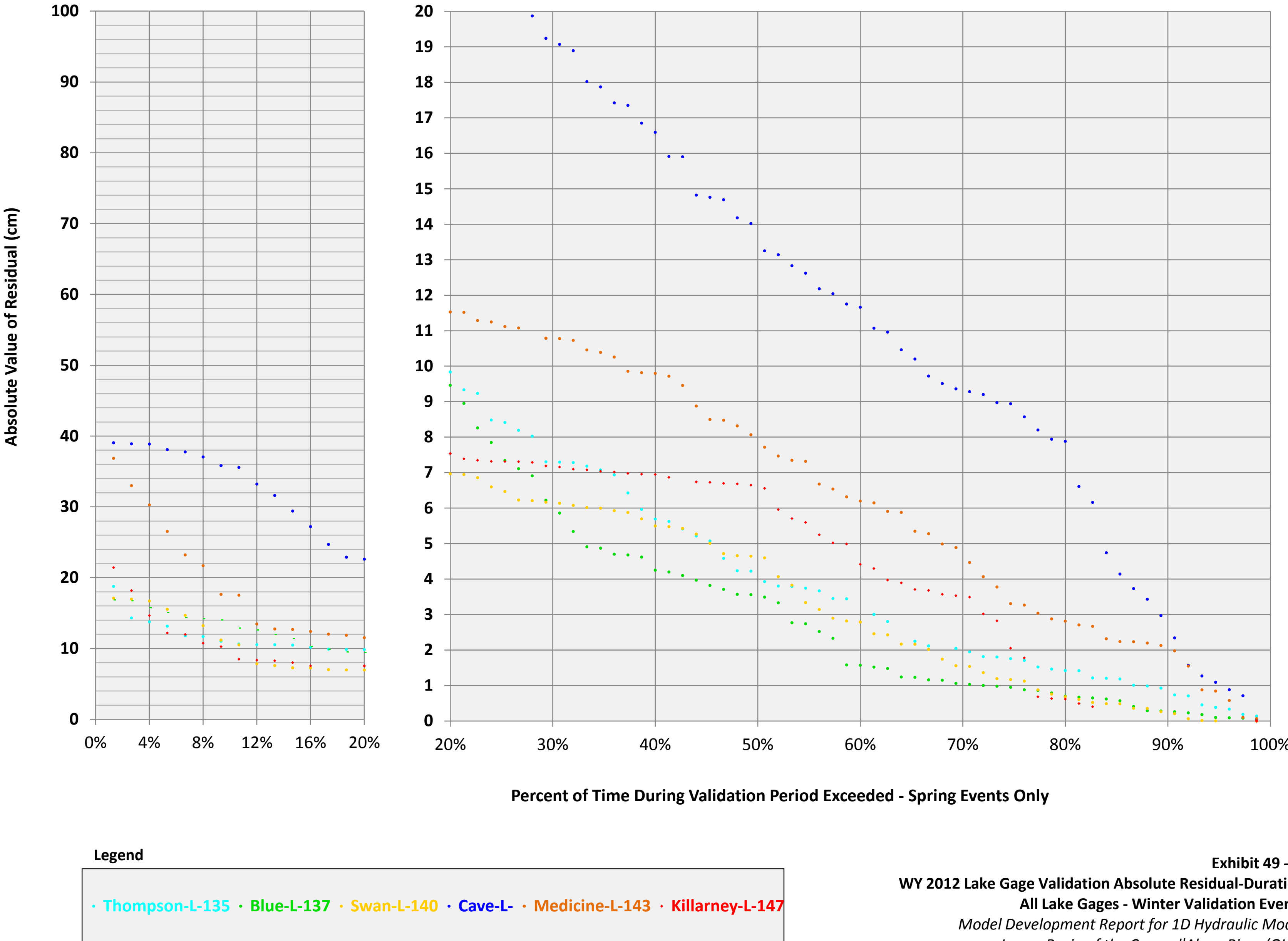


Exhibit 49 -v. i

WY 2012 Lake Gage Validation Absolute Residual-Duration

All Lake Gages - Winter Validation Events

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

EXHIBIT 50.a. FLOW RESIDUAL STATISTICS
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

USGS Gage		Max		Min		Mean		Standard Deviation		Median	
		c	*v*	*c*	*v*	*c*	*v*	*c*	*v*	*c*	*v*
Cataldo	Absolute Residual (cms)	20.4	1.4	-58.5	-63.1	-5.0	-7.6	12.8	9.5	-1.3	-3.8
	Residual %	76%	5%	-11%	-30%	2%	-3%	11%	4%	-1%	-3%
Harrison	Absolute Residual (cms)	127.9	138.9	-124.8	-96.4	-4.8	0.4	31.2	23.9	-2.5	1.3
	Residual %	38%	69%	-31%	-31%	-1%	4%	12%	15%	-1%	1%

Statistics generated from flow events (only) as defined in Exhibit 25

EXHIBIT 50.b. WATER SURFACE ELEVATION RESIDUAL STATISTICS
Model Development Report for 1D Hydraulic Model
Lower Basin of the Coeur d'Alene River (OU3)

Level Logger Gage		Max (cm) *c*	Max (cm) *v*	Min (cm) *c*	Min (cm) *v*	Mean (cm) *c*	Mean (cm) *v*	Standard Deviation (cm) *c*	Standard Deviation (cm) *v*	Median (cm) *c*	Median (cm) *v*
Thompson Lake	River	3.8	5.2	-9.1	-4.1	-0.6	0.0	0.9	1.4	-0.6	-0.1
	Lake	7.1	16.4	-22.2	-18.8	-0.8	-0.2	2.6	4.3	-0.4	-0.2
Blue Lake	River	4.0	3.8	-13.3	-8.4	-0.1	0.9	1.2	1.4	0.0	1.1
	Lake	9.4	21.3	-19.1	-19.3	-0.4	0.4	3.1	5.1	-0.2	-0.1
Swan Lake	River	10.2	5.3	-13.6	-14.8	-0.3	-0.9	1.7	2.1	-0.2	-0.8
	Lake	16.1	6.0	-26.9	-17.1	0.0	-1.7	3.7	3.2	-0.2	-0.6
Cave Lake	Lake	10.9	9.2	-92.1	-49.6	-4.3	-7.0	10.6	11.3	-1.4	-1.4
Medicine Lake	River	17.9	12.5	-26.3	-20.5	-0.2	-0.5	2.7	2.9	0.0	-0.7
	Lake	12.9	15.3	-72.4	-63.9	-3.4	-1.8	9.7	7.8	-1.0	-0.6
Killarney Lake	River	22.7	14.1	-20.7	-23.8	-0.5	-0.8	3.3	3.9	-0.6	-1.3
	Lake	19.2	12.2	-22.7	-21.4	0.7	-0.3	3.6	3.4	0.8	-0.7
Black Rock	River	25.7	17.6	-24.3	-25.3	-0.3	-0.7	3.8	4.3	-0.6	-1.8
Below Bull Run*	River	16.3	NA	-27.9	NA	-0.4	NA	4.8	NA	-1.6	NA
Above Bull Run*	River	18.0	NA	-25.6	NA	-0.3	NA	5.1	NA	-1.7	NA
Dudley	River	26.3	16.5	-27.3	-31.2	-1.0	-2.5	4.5	4.9	-1.6	-3.7
Dredge Pool*	River	23.4	NA	-34.2	NA	2.9	NA	5.3	NA	2.7	NA
Confluence*	River	10.4	NA	-13.8	NA	-0.4	NA	4.4	NA	-0.6	NA

c – calibration period (WY 2011, except for loggers with * for which calibration period was WY 2012)
v – validation (WY 2012)
Highlighted cells indicate loggers for which the difference between the validation central tendency statistic and calibration central tendency statistic was at least 1.5 cm.

Model Element	Sensitivity	Uncertainty
Computational time step	**Moderate**. Flow at Harrison shows little to no change to computational time step. However, increased instability and model crashes may occur at time steps other than 1 minute. Decrease in time step can reduce model run time.	Not applicable.
Theta	**Low**. Change in Theta between 0.6 and 1.0 resulted in no change to model results at Harrison, and no change to model stability. HEC-RAS Users Manual (U.S. Army Corps of Engineers, 2010b) reports that a value of 1.0 results in less reliable results but higher stability, and a value of 0.6 results in more reliable results and lower stability. A value of 0.8 was selected and used for model runs.	**Moderate**. 0.8 was used; 0.6 is reported to produce more reliable results. However, use of 0.6 in this model shows no change in results at Harrison.
Lateral Structure flow stability factor	**Moderate** Increasing this model factor from 2 to 3 resulted in slightly lower flows leaving the channel across lateral structures. It also resulted in small differences (1 to 4 cm) in the main channel water surface elevation.	**Moderate** HEC-RAS documentation reports that a value of 1 is more accurate, but a value of 3 is more stable. A value of 2 was chosen as a compromise between model stability and accuracy.
Weir flow submergence decay exponent	**Moderate** Increasing this model factor from 2 to 3 resulted in slightly lower flows leaving the channel across lateral structures. It also resulted in small differences (1 to 4 cm) in the main channel water surface elevation.	**Moderate** HEC-RAS documentation reports that a value of 1 is more accurate, but a value of 3 is more stable. A value of 2 was chosen as a compromise between model stability and accuracy.
Weir coefficient of lateral structures and storage area connections	**Low**. The weir coefficient of the lateral structures and storage areas was adjusted as part of attempts to calibrate the exchange of flows between the river and the lateral lakes. These adjustments did not result in noticeable differences in the modeled river/lake exchange.	**Moderate**. The terrain dividing the lateral lakes and river, represented in the model by lateral structures and storage area connections (acting as weirs) are complex features represented by simplified model elements. Attempts were made during model construction to capture the highest portion of the LiDAR-derived terrain that controls flow. However, the LiDAR imperfectly captures the vegetation on these complex surfaces, and the model even more imperfectly represents this surface when assigning weir flow. In general, the terrain being represented by weir coefficients is consistent with a very low weir coefficient (1.1 was typically used, where the recommended range for a standard concrete broad crested weir is 2.6-3.1).
Tie channel geometry	**High**. Tie channel geometry has large effect on the exchange of flows between the river and lateral lakes. This parameter was used as a primary calibration factor, as summarized in Section 5.5, Water Surface	**Moderate**. The exchange of flows between the river and lateral lakes is controlled by the smallest cross sectional area, and the highest thalweg elevation of a given tie channel. Attempts were made to survey the

Model Element	Sensitivity	Uncertainty
	Elevation Calibration. See Exhibit 28 for a summary of how these geometries were changed as part of calibration.	thalwegs of the tie channels using rod-shot or single-beam survey methods. However, it is impossible to know that the actual thalweg was surveyed, or that the smallest channel cross sectional area was captured. In addition, changes to vegetation in these channels may change the effective area used to convey flow. While most of the tie channels have relatively homogeneous geometry and structure, there is high uncertainty that the controlling tie channel geometry is captured in the terrain model from which the model geometry is derived.
Bridge geometry	**Low**. Although not explicitly analyzed, the bridge geometry is expected to have little effect on overall flow hydraulics. During the highest flow in the 2004–2011 period (May 2008), the water surface elevation was below the low chord on all the model bridges. The piers included in the model, whose geometry is estimated from photos, are small in comparison with the total flow area of the river, and thus have a small contribution to the river flow capacity.	**Moderate**. Bridge geometry was not surveyed. The elevation of the bridge deck was derived from LiDAR, and has low uncertainty. The elevation of the low chord, number of piers, and dimensions of piers were all estimated based on photos from the field. Bridge deck thickness and pier dimensions are accurate only within the order of 1-3 m.
Bankline geometry (Lateral structure and other floodplain geometry, derived from LiDAR)	**High**. Overbank flows and flow exchange occurring primarily during spring high flow events have a large effect on overall attenuation, filling of the lateral lakes, and overall channel flow.	**Moderate**. Lateral structure geometry is derived from LiDAR data. LiDAR data are generally believed to have high quality. However, they may inaccurately represent the terrain surface due to the presence of vegetation and other obstructions.
Cross section geometry	**High**. Channel conveyance is function of cross section geometry. Lower conveyance results in increased water surface elevations, increased floodplain conveyance, and changes to calibration parameters.	**Low**. Cross section geometry derived from the portions of the DTM created with multi-beam bathymetry. This survey data density and accuracy is high, resulting in low uncertainty.
Channel and floodplain roughness	**High**. Channel and floodplain conveyance is function of surface roughness. Lower channel conveyance results in increased water surface elevations, increased floodplain conveyance, and changes to calibration parameters.	**Moderate.** Channel and floodplain roughness are spatially heterogenous and can only truly be determined through detailed direct field measurements. Instead of direct measurement of roughness, typical relationships between vegetation type, channel surface topography and substrate size were applied to the best available data for a starting roughness. These relationships are developed in other river systems, and may not apply directly to the Coeur d'Alene. In the case of channel substrate size and topography, these best available data were only available at a few discreet locations; interpolation and extrapolation was necessary. This roughness was then modified as a primary

Model Element	Sensitivity	Uncertainty
		calibration parameter. Adjustments made during the calibration process likely represent uncertainties in many model parameters and boundary conditions (and actual roughness). Using this calibration method, roughness is used as a surrogate for all energy losses in the model.
Downstream Boundary Condition	**High**. As observed by the differences in behavior of the river at similar flows but different downstream lake levels, the lower boundary condition (water surface elevation at Highway 97) has a large effect on model results.	**Moderate**. Prior to 2004. Coeur d'Alene Lake level determines the degree of backwater effects for two thirds of the model, affecting flow and water surface elevations throughout the model. Lake level data at Harrison is unavailable prior to 2004. Model runs prior to 2004 will need to use data recorded at a gage located near the City of Coeur d'Alene and may need to be adjusted as a function of flow rates recorded in the Lower Basin. Model scenarios for periods prior to 2004 will have a higher degrees associated with the downstream boundary condition which directly effects the model predicted water surface elevations upstream, specifically for the areas affected by backwater. **Low**. After 2004. Water surface elevation measurements are not available at the downstream model boundary, but are instead measured at the USGS Gage at the Springston Bridge, approximately 2,960 m upstream of the downstream boundary condition. The model was iterated to estimate losses along these 2,960 m, which range from close to 0 during summer low flows, to over 0.4 m during some winter high flows. Because there are no calibration points below the Springston Bridge, there is no way to know how well the model calculates these losses.
Upstream Boundary Condition	**High**. Flows from the North Fork and South Fork comprise 90 percent of the flow entering the model. All model results are thereby extremely sensitive to these inputs.	**Low**. Flows from the North Fork and South Fork are measured by the USGS.
Braided Modeling Reach cross section geometry – interpolated cross sections and pilot channel.	**Moderate**. Interpolated cross sections were added to the model geometry in sections of the model where large changes (>0.1m) are observed in low flow water surface elevation between cross sections. These interpolated cross sections are based on nearby cross section geometry cut from the HEC-GeoRAS DTM. Adding interpolated cross sections is a standard modeling practice. Addition of these cross sections helps to stabilize the model.	**Low.** Given the coarse nature of the DTM along the braided modeling reach (based on single-beam bathymetry as opposed to multi-beam bathymetry used in much of the main channel), the uncertainty of interpolated cross sections and use of pilot channels is no greater than the uncertainty of the DTM interpolation resulting from use of single-beam bathymetry. Due to the relatively steep longitudinal

Model Element	Sensitivity	Uncertainty
	Similarly, adding pilot channels is a standard modeling practice in low-flow and steep channels. These pilot channels are narrow relative to moderate flows (typically less than 1m wide), and have little effect on water surface elevation (especially that during moderate and high flows).	profile of the braided reach, small errors in the water surface elevation of the braided reach have little effect on the remainder of the model.
Ungaged tributary inflows	**High**. Timing, volume, and attenuation of the ungaged tributary flows have a large effect on model flows at Harrison, on water surface elevation in the lateral lakes, and on the flow exchange between the lateral lakes and the river. These flows have a moderate to low effect on water surface elevations at river water surface elevations.	**High**. Ungaged tributary flows are based on results from a HEC-HMS hydrologic model. This model was calibrated using gaged flows at Latour Creek, the largest creek in the Lower Basin, which is not representative of flows in shorter and smaller creeks elsewhere in the basin. The precipitation data used in this HEC-HMS model is from a discrete gage at Enaville, just east of the Lower Basin, and may not represent the complex and localized weather patterns that occur in the basin. The weather in Harrison is often quite different than that at Enaville. The snowmelt data used in the HEC-HMS model are from a snowmelt gage in Kellogg, even farther outside the basin than the precipitation gage in Enaville. The Kellogg gage is higher than many parts of the basin (707 m vs. 650 m at Harrison), and does not reflect lower and mid-elevation snowmelt. After calibration of the HEC-HMS model, the resultant flows were further reduced by a factor of 0.375 during flow calibration, representing the high uncertainty with these flows.
Braided Modeling Reach minimum flow	**Moderate.** Inclusion of minimum flows for stability purposes in artificially raises overall river flows in relation to those observed in the field. This can affect the draining of storage areas in the winter and can affect calibration to extreme low flow.	**Low**. In general, the Lower Basin 1D Hydraulic Model is used for moderate and high flow conditions such as flood events. Modifications to low flow periods have negligible effect on the high flow model periods of interest.
Storage Area Initial conditions	**High.** Model stability is impacted by storage area initial conditions. Filling or emptying of storage areas too rapidly to reach equilibrium with the river can cause the model to crash. It can also cause a large amount of flow to be inserted into or removed from the river, resulting in large flow imbalances compared to gaged flow.	**High.** Only 6 of the 36 modeled storage areas have level-loggers. Water surface elevations of the remaining 30 storage areas at the beginning of the model run are unknown. In addition, model runs that start before the installation of level loggers (4/14/10) are not known. Storage area and river levels in the model tend to equilibrate in one month (or less), so this uncertainty can be mitigated by starting the model at least one month prior to the date of desired results, or by using initial conditions imported from a previous model run that includes the desired model start date.

Model Element	Sensitivity	Uncertainty
Storage Area storage-elevation curves	**High.** Large amounts of storage areas provided by storage areas in the model. These attenuate high flows, elevate low flows, and tend to flatten the hydrograph. The capacity of these storage areas are defined by storage-elevation curves.	**Low** to **Moderate**. Storage area bathymetry was surveyed, primarily using single-beam and rod-shot survey technology. These methods do not provide high density survey data; but the storage areas tend to be relatively shallow and have homogeneous
Fourth of July Creek Pump Station operations	**Low.** Other than the level Storage Area 1249 – Canyon Marsh, flows from the FOJC pump station have little impact on other aspects of the model.	**High**. Information provided by the operator of the FOJC pump station shows that the station does not have a uniform or detailed pump curve. The pump station is a series of multiple pumps, the capacity and properties of which are not known. The station tends to be operated based on season and the individual and specific capacity for land owners in the Canyon Marsh area to have their land flooded. Pump operations were assumed to pump the peak 3-day average from the HEC-HMS model: 19.28 cms.
Level Logger Datums	**High.** Much of the model calibration focused on adjusting model parameters to get river and lateral lake water surface elevations to match level logger data. If these level logger data are incorrect, model calibration results in model behavior that does not represent river behavior in the field. In this case, calibration parameters (such as roughness and tie channel geometry) may be adjusted incorrectly.	**Moderate to High**. The methods used to survey the logger elevations acknowledge accuracy that is at best 2 cm, and often greater than 2 cm. More accurate survey is not feasible given site conditions. Repeat surveys of many of the logger locations has reduced uncertainty at some locations, and has shown widely varied results at other locations. Environmental and human factors can shift loggers (and thus logger datums) both vertically and horizontally. To mitigate datum uncertainty, logger datums were adjusted to meet a best-fit straight line that likely occurs during low river flows and high lake levels.
Floodplain Conveyance	**Moderate**. Conveyance of in the floodplain affects water surface elevations and flow rates in the main channel. Short-circuting through the floodplain due to instantaneous filling/emptying of storage areas results in less accurate flood timing (and often an exaggeration of the peak flood). Sensitivity analysis conducted by artificially removing lateral structures resulted in the similar magnitude flows leaving the channel and being conveyed in the floodplain, but these flows leaving over different bank locations.	**High.** HEC-RAS calculates an instantaneous filling and draining of storage areas over lateral structures and storage area connections that behave like weirs. This process does not account for the resistance to flow and energy losses in the storage areas. This process generates high uncertainty about the floodplain flows. Detailed analyses indicate that the magnitude of floodplain flows may be exaggerated, but that the location is more certain.

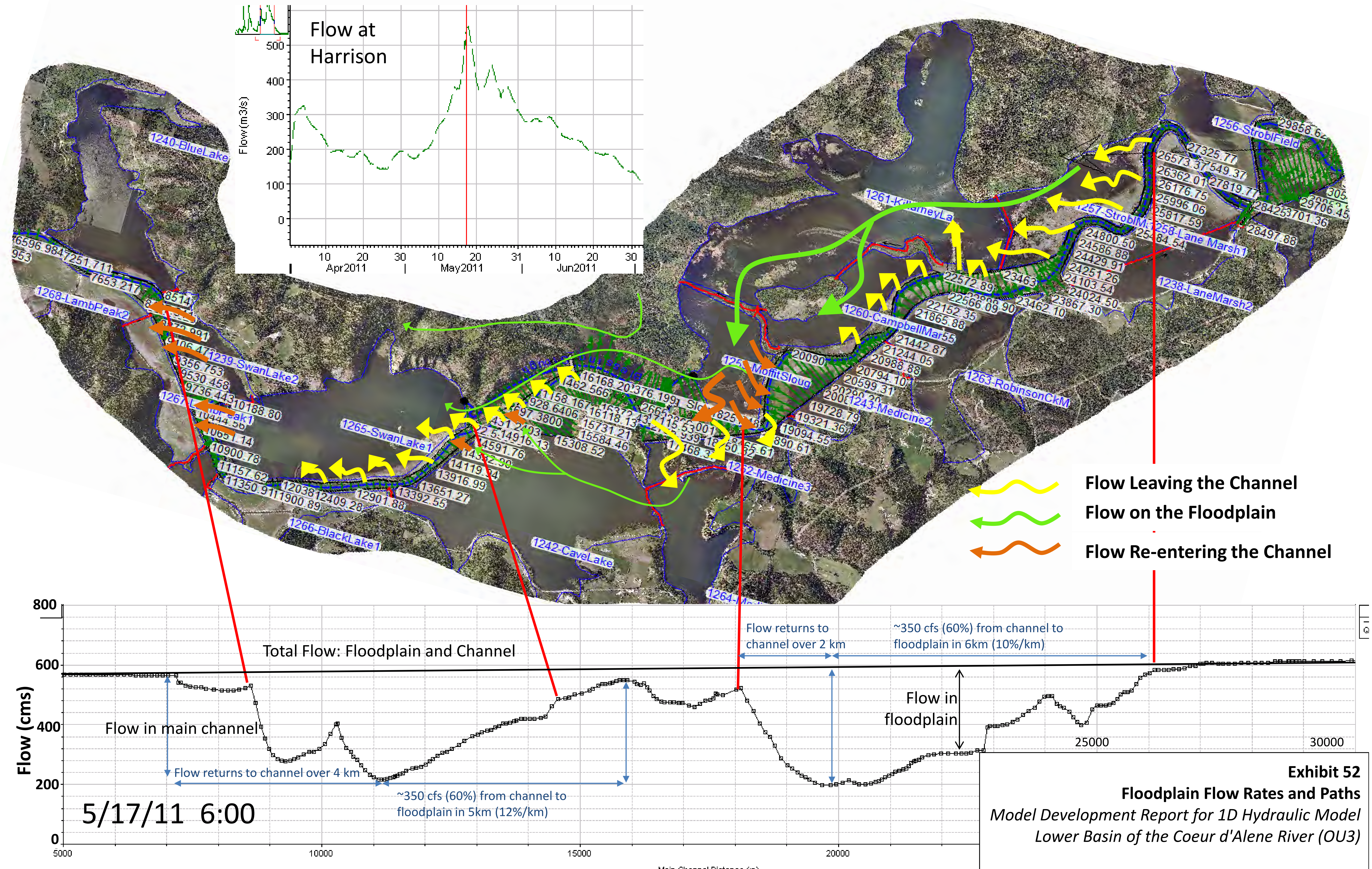


Exhibit 52

Floodplain Flow Rates and Paths

Model Development Report for 1D Hydraulic Model

Lower Basin of the Coeur d'Alene River (OU3)

Attachments

Attachment A – Glossary

Attachment B – USGS Flow and Stage Data Processing

Attachment C – Electronic files of HEC-RAS Model, including Boundary Conditions and Level Logger Data

Attachment A
Glossary

ATTACHMENT A

Glossary (Expanded)[5]

Adaptive management – A systematic, deliberate, and defined methodology for defining and implementing management policies to address complex problems under a relatively high degree of uncertainty regarding the characterization of an environmental system and the impact or outcome of remedial actions.

Aggradation – Sediment deposition in the bed of a river resulting in an increase in the average or minimum bed elevation. Aggradation reduces the elevation difference between the channel bed and the floodplain surface, thereby increasing the potential for increased amounts and frequency of flow.

Base flow – The water present in streams and rivers that is not due to runoff from rain or snowmelt. Base flow is the proportion of stream flow that comes from discharge of groundwater to the stream or river, or that portion of the flow that has been delayed by slow passage through lakes or other water bodies.

Bathymetry – The measurement of water depths and the estimation of the surface elevation of the land beneath water features. When bathymetric and topographic (the land surface above water features) data are combined, a complete picture of the elevation of the ground surface can be generated.

Bed form – Bed forms are features on the channel bed (undulations and perturbations in bed surface elevation) that form in response to hydraulic and sediment interactions.

BEMP – This is an acronym for the Basin Environmental Monitoring Plan developed by the U.S. Environmental Protection Agency in 2004. The BEMP describes data collection efforts intended to assess long-term changes to water, sediment, and biological systems to help manage cleanup efforts.

Boundary conditions – Refers to required input data for the model representing conditions at the upstream, downstream, and lateral edges of the model. For example, the inflowing sediment load is a boundary condition at the upstream end of the model, and the lake elevation is an important downstream boundary condition.

Calibration – The process of adjusting the model input parameters to replicate observed or physically realistic conditions. Model input parameters are adjusted during the calibration process, based on the difference between modeled and observed values, until the model results most closely match observed conditions at all available calibration locations, and until the model results in other locations where calibration data are unavailable appear reasonable.

Calibration Reach – See *Reach*

Cohesive/non-cohesive – These terms describe the degree to which sediment particles adhere together. Cohesive soils are those that have relatively high shear strength when dry and high cohesion when wet, characteristics that are typical of fine-grained clay-rich soils and sediments.

Curve number (CN) – This hydrologic modeling parameter is used to characterize the relative permeability of the ground surface and controls the predicted volume of runoff for an increment of rainfall.

Digital Terrain Model (DTM) – A DTM is a three-dimensional (3D) digital representation, typically a raster grid of elevation values, of the land surface, and commonly includes both topographic and bathymetric surfaces.

Dune – A particular type of bed form, consisting of a sand wave transverse to the direction of flow. Dunes typically migrate downstream by erosion of sand from the upstream slope, and deposition on the downstream slope.

Erosion – The group of processes involved in wearing away of soil, sediment, or rock, which can include chemical as well as physical weathering.

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[5] The Glossary includes terms related to simulation modeling in the Lower Basin in addition to those specifically addressed in this document, so that it can provide reference value in other applications such as workshops and reviews of related documents.

Floodplain – The flat land adjacent to a river channel that is inundated by water during high river flows. This land is underlain by alluvial sediment that has been deposited during previous flooding. Alternatively, floodplain may be defined in a hydraulic sense as the extent of land that can be inundated by floods of a certain magnitude (for example, the 100-year floodplain).

Gage (or gaging station) – A device for measuring flow parameters such as water elevation, velocity (as at a stream gage), or precipitation (rain gage).

Geographic Reach – See *Reach*

Grain size – See *Particle size*

HEC-DSS – The United States Army Corps of Engineers' (USACE) Hydrologic Engineering Centers Data Storage System is a database system designed to efficiently store and retrieve scientific data that is typically sequential. Such data types include, but are not limited to, time series data, curve data, spatially-oriented gridded data, and others. HEC-DSS files are used and created by computation models and other software created by the USACE's Hydrologic Engineering Center, such as HEC-DSSVue, HEC-HMS, and HEC-RAS.

HEC-DSSVue – The visual utilities program created by the USACE that allows users to plot, tabulate, edit, and manipulate data in a HEC-DSS database file.

HEC-HMS – The Hydrologic Engineering Centers Hydrologic Modeling System created by the USACE. See Hydrologic modeling.

HEC-RAS – The Hydrologic Engineering Centers River Analysis System, a 1D model created by USACE. See One-dimensional (1D) hydraulic modeling.

Hydraulic – Relating to fluid in motion. Local hydraulics refers to the physical characteristics of flow (for example, velocity and depth) at a specific location. Hydrology (the flow of surface water) and topography (the surface over which the flow travels) both influence hydraulics.

Hydraulic (or hydrodynamic) model – A mathematical representation of water flow over a surface. A hydraulic model requires a representation of the topography (see DTM) and water discharge as input, and uses the conservation equations for mass and momentum of water to compute the spatial distribution of hydraulic characteristics (for example, water surface elevation, depth, velocity, and shear stress). A one-dimensional (1D) hydraulic model computes hydraulics down the channel, whereas a two-dimensional (2D) hydraulic model accounts for flow in both the downstream and cross-stream directions.

Hydrograph – A graph of water characteristics (for example, flow, velocity, or stage (river height)) over time. For a particular flood event, the portion of the hydrograph before the peak flow is referred to as the "rising limb," and the portion after the flow peak is called the "falling limb." The peak of the hydrograph is typically used to characterize the magnitude of a flood.

Hydrologic modeling – A type of computational modeling that estimates the hydrograph in a channel given precipitation and watershed characteristics. Hydrologic models simplify a very complex and spatially heterogeneous set of processes and represent them with simple aggregated parameters such as the "curve number" and "lag time," which can be calibrated or estimated for relatively large areas. In general, hydrologic models account for: rainfall interception (such as by the tree canopy), water infiltration into the soil, ponding on surfaces, and downstream routing. The USACE hydrologic model HEC-HMS is used for hydrologic modeling of the Lower Basin of the Coeur d'Alene River.

Hydrologic soil group – A classification system for soil hydrologic properties developed by the Natural Resource Conservation Service, which conducted and compiled the Soil Survey Geology (SSURGO) database. These soil group classifications are used in hydrologic modeling to determine an area's curve number.

Hydrology – The science of the water cycle, including factors such as precipitation, infiltration, runoff, and evaporation. Hydrology deals with the movement of water on the earth's surface (river flows) and also in the subsurface (groundwater).

Lag time – The time delay from the midpoint of a rainfall event to the peak of runoff (peak of the hydrograph) in a given stream. In a hydrologic model, the lag time parameter controls the shape of the hydrograph, as opposed to the volume of flow. Lag time can be calculated based on watershed slope, channel length, and average velocity; however, in practice lag time is often calibrated using known rainfall and measured runoff hydrographs.

Lateral channel (or, tie channel) – In the context of this project, these terms refers to a natural or manmade passage providing hydraulic connection between the main river channel and a lateral water body such as a lateral lake or marsh. The elevation, cross sectional area, and profile of lateral channels affect the rate at which water flows into and out of off-channel water bodies.

Lateral lake – A lake or marsh separated from the main channel by natural or manmade levees or embankments, and which typically drains or fills through culverts or lateral channels (tie channels).

Levee – A natural or artificial embankment along a river between the channel and floodplain. Natural levees are broad ridges that slope away from the river channel and are composed of the coarsest portion of the suspended sediment load, deposited by the river during flooding. An artificial levee is an embankment built along a river or other water body to prevent adjacent land from being flooded.

Manning's n – See *Roughness coefficient*

MIKE 21C – The 2D model created by the Danish Hydraulic Institute (DHI). See *Two-dimensional (2D) hydraulic modeling*.

Modeling Reach – See *Reach*

One-dimensional (1D) hydraulic modeling – A type of computational modeling in which water flow processes are modeled in one dimension only (in the downstream flow direction). Velocity and shear force values are averaged over the width and depth of each cross section. The USACE 1D model HEC-RAS is used for 1D modeling of the Lower Basin of the Coeur d'Alene River.

Particle size (or, grain size) – Approximation of the size of individual soil or sediment particles, usually measured in millimeters (mm) for sand and coarser material or micrometers (µm) for clay and silt. Particle size of the bed material and inflowing sediment are critical parameters required for input to the sediment transport model.

Permeability – The capacity of rock, soil, or sediment for transmitting fluid. Permeability of soils is closely related to porosity, which is a measure of the amount of space between grains. The infiltration capacity of soil is related to permeability, but is also affected by the type of land cover. These factors are the basis of the curve number used in hydrologic modeling.

Reach – A section of a river between two specific points. For the purposes of modeling or evaluating rivers, a reach can be delineated as a subsection of the river with relatively consistent hydraulic, hydrologic, or geomorphic characteristics. Within the context of the 1D model report, three different types of reaches are used: geographic reaches (4), modeling reaches (7), and calibration reaches (11). All three sets of reaches are shown on Exhibit 15. Geographic reaches define geographically unique and separate areas and are used in many of the other Enhanced Conceptual Site Model documents. Modeling and calibration reaches are unique to the 1D model and are used to define location of model elements (modeling reach) and to define the portion of river affected by calibration to a given gage location (calibration reach).

Reliability – In the context of computational model calibration and validation, reliability refers to the level of accuracy and robustness for specific model outputs. Reliability refers to model outputs, while uncertainty refers to specific model inputs and model processes.

Reservoir – In the context of this project, any off-channel area that can be filled and drained of water as river levels fluctuate. The hydraulic model treats off-channel water bodies as storage reservoirs, which can thereby affect the downstream propagation of floods by attenuating or augmenting flow in the channel.

Roughness coefficient – A measure of flow resistance, or friction, over a surface that causes energy losses. The roughness coefficient accounts for the combined resistance from form drag caused by larger scale features like bends, bars, and bedforms, and skin friction, which is attributable to friction on individual particles comprising the earth's surface. Floodplain and channel roughness are required inputs to the hydraulic model. In the case of the 1D model, Manning's n is used as the roughness coefficient.

Scour – The process of erosion controlled by water flowing over a bed composed of mobile sediment.

Sediment transport – The physical process of movement of sediment particles by hydraulic and gravitational forces. In rivers, sediment transport can be divided into distinct sub-processes. These include suspended sediment transport, in which finer-grained particles are carried high in the flow by upward mixing of turbulent eddies, and bedload transport, in which particles roll, slide, or bounce near the channel bed.

Sensitivity analysis – The process of determining which inputs, model settings, and parameters have the greatest influence on model results, as well as determining the magnitude of output changes relative to respective input changes (for example, does a small change in a model input change results by a negligible amount or significant amount, and is this expected and reasonable?). Sensitivity analysis combined with uncertainty analysis provides a meaningful method of classifying the reliability of model results.

Shear stress – Force exerted by the movement of water across a surface, measured parallel to flow direction. In general, when the shear stress on the bed exceeds the critical shear stress for the initiation of motion, particles begin to move.

Snow melt – The contribution to surface water flow derived from melting snow, as distinct from rainfall.

Spatial resolution – In the context of Lower Basin modeling, this refers to the size of the grid cell or other computational unit used in a given analysis.

Structure (or hydraulic structure) – In the context of hydraulic modeling, any submerged or partially submerged feature that disrupts the flow of water. Examples of structures include culverts, weirs, dams, embankments, or other such elements.

Suspended load – The portion of the sediment load that is carried high in the flow without contact with the bed for a considerable period of time. Suspended particles settle downward due to gravity, and are mixed upwards by turbulent eddies.

Temporal scale – Temporal scale refers, in this context, to the time scale, or duration, associated with a simulated event.

Tie channel – Also called lateral channel, a channel that connects a lateral lake (also called floodplain lake) to the main channel of a river, allowing transfer of water and sediment between these two water bodies. These channels can be formed naturally or by humans, and can have a large impact on the hydraulics of a river system.

Time step – Also called computational time step, the interval over which calculations in a computation model are made. Some computation models are quite sensitive to the time step. Time steps in typical hydrodynamic and hydrologic models can range from less than 1 second to more than 1 month.

Time of concentration (T_c) – The time required for a particle of water to travel from the furthest point in the watershed to the outlet. The time of concentration controls timing and magnitude of runoff but not the total volume, and is closely related to lag time.

Topography – The elevation of the land surface above the surface of water. Topography is a primary control on hydraulics and sediment transport during flooding, and is therefore a key element of 2D modeling.

Two-dimensional (2D) hydraulic modeling – Hydraulic modeling that considers both downstream and cross-stream hydraulics, within the channel and on the floodplain. The Danish Hydraulic Institute (DHI)'s 2D model MIKE 21C is used for 2D modeling of the Lower Basin of the Coeur d'Alene River.

Validation – The process of using an independent dataset (not used in the calibration process) to independently check the calibration of a model. Validation indicates how well the model is calibrated and how well the model is able to replicate observed conditions.

Velocity – Rate and direction of movement of an object, such as water. The units of velocity for water are generally expressed in terms of feet per second, or meters per second (generally in the downstream or cross stream direction).

Vertical Datum – Also called Geodetic datum, this is a reference from which vertical measurements are made. Multiple vertical datums have historically been used in the Coeur d'Alene River Basin, including North American Vertical Datum of 1988 (NAVD 88), the National Geodetic Survey Datum of 1929 (NGVD 29), and the Avista Datum (also called Washington Water Power datum). The National Geodetic Survey's VERTCON (https://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl) is used for point conversions between NGVD 29 and NAVD 88, the conversion of which varies across the basin. The difference between NGVD 29 and NAVD 88 at the USGS gages in the Lower Basin range from 1.11 meter (m) to 1.17 m (Berenbrock and Tranmer, 2008). The lake gage at Coeur d'Alene has a difference of 0.24 m. The Avista datum is 0.930 m lower than NGVD 29 at Post Falls Dam (Black, 2003).

Water budget – An accounting for the inflow, outflow, and change in storage within a defined hydrologic unit, such as a drainage basin. Water budgets generally account for precipitation, evaporation and transpiration, and stream runoff.

Attachment B
USGS Flow and Stage Data Processing

ATTACHMENT B

U.S. Geological Survey Flow and Stage Data Processing

This document summarizes data sources and data processing steps for 15-min discharge and gage height time series for the following gages:

- 12413000: North Fork Coeur d'Alene River at Enaville, ID
- 12413470: South Fork Coeur d'Alene River nr Pinehurst, ID
- 12413500: Coeur d'Alene River nr Cataldo, ID
- 12413860: Coeur d'Alene River nr Harrison, ID

Data Sources

All 15-min discharge and gage height data was downloaded from ftp://ftpext.usgs.gov/pub/wr/id/boise/rdickinson/Woidt/. The ftp site was set up by Ross G Dickinson (USGS Boise, ID 208-755-6476 rdickins@usgs.gov) and contained discharge and gage height for the entire period of record for each gage (typically through 12 Feb 2012). Text files were generally ~10-20 MB for each gage.

Data Processing Steps

Excel

1. Load text file data into Excel (tab delimited)
2. Create a separate Excel file for each 10 years of data (larger files were cumbersome to calculate)
3. Correct for daylight savings time. If timestamp is "PDT" then subtract 1 hour to convert to PST. All times in PST were required. Round each time to the nearest 15-min interval.
4. Create a column and populate with date/time stamps that are not missing any values. The time interval was 15-min.
5. Use VLOOKUP function to populate the continuous time series with observed discharge. Use the "False" option to require an exact match for the date/time stamps. Missing date/time stamps from the original data will populate this new time series with #N/A. (*Note: the VLOOKUP function with the "False" requirement takes the longest to calculate…~5 mins per spreadsheet). In the end, this spreadsheet is typically ~30 MB.
6. Copy the continuous date/time series and populated discharges into a new spreadsheet (to avoid any time delays for recalculation of the VLOOKUP function)
7. Use an IF statement to replace #N/A values with blank ("") values.
8. Use an IF statement to identify missing cells (0 for not missing, 1 for missing)
9. Use an IF statement to count the number of continuous missing cells in one day. For 15-min data, the maximum number of missing cells for an entire day is 96.

10. Count the number of whole missing days (can refer to cells with a value of 96)
11. Count consecutive missing days
12. Count the maximum string of missing days
13. Summarize the date ranges where complete days are missing
14. DISCHARGE ONLY - For dates with complete days missing, use a VLOOKUP command to populate each 15-min interval with the daily average (requires daily flows to be added to the spreadsheet for reference). All values for completely missing days are then populated with a constant, daily average discharge.
15. DISCHARGE ONLY - Use an IF statement to create a combined time series using the observed 15-min data (where available) and the daily average discharge applied to 15-min intervals (for days with all data missing). For days with incomplete records (missing data but not a whole day gap) use an IF statement to write an "M" in the cell ("M" is a recognized HEC-DSS missing code). This spreadsheet is typically ~35 MB.

HEC-DSS

1. For discharge, select the Data Entry → Manual Time Series Option
    a. Part A – Gage name
    b. Part B – Gage ID
    c. Part C – Discharge
    d. Part D – Fill in start date/time
    e. Part E – 15-min
    f. Part F – USGS-CH2MHILL (to denote USGS source data modified by CH2M HILL)
2. For gage height, select the Data Entry → Manual Time Series Option
    a. Part A – Gage name
    b. Part B – Gage ID
    c. Part C – Stage
    d. Part D – Fill in start date/time
    e. Parte E – 15 min
    f. Part F – USGS-CH2MHILL (to denote USGS source data modified by CH2M HILL)
3. Use copy-paste to take data from the Excel spreadsheet to HEC-DSS. This usually takes ~10 minutes for each 10 years. After each "paste" check that the ending date/time is correct. Since there are no missing time intervals in the Excel spreadsheet, the last date/time in DSS should match the last date/time from Excel.
4. Select Graphical Edit → Estimate Missing → Accept. This linearly interpolates between missing values. Since all of the missing values are sub-daily, then linear interpolation is expected to be sufficient to capture the hydrograph characteristics.
5. Save the HEC-DSS record.

6. To convert gage height to WSEL, use the math functions in HEC-DSS. Add a constant value based on the USGS website information for adjusting gage heights to NAVD88. Save the new record and change C-Part to “WSEL”. Conversions used are:
    a. 12413500 (Cataldo) = +2103.67
    b. 12413860 (Harrison) = +2103.71

Discharge Data Notes

The following table summarizes the data sets (missing values, period of record, special notes, etc.)

Gage ID	Name	Time Period	% Missing	Periods Missing Complete Days	Longest Missing Days	Notes
12413000	NF – Enaville	30 Sep 1986 23:30 – 31 Dec 1989 23:45	51.7	14 Feb 1988 – 23 Feb 1988 17 Aug 1988 – 18 Sep 1988	33	High % missing since most of data is 30-min interval
		01 Jan 1990 0:00 – 31 Dec 1999 23:45	41.4	24 Mar 1991 – 25 Mar 1991 30 Apr 1991 – 29 Sep 1994 10 Jan 1998 – 13 Jan 1998 14 Jun 1998 – 15 Jun 1998 20 Jun 1998 – 28 Jun 1998	1249	High % missing due to some 30-min interval and long (1249 days) missing stretch
		01 Jan 2000 0:00 – 31 Dec 2009 23:45	0.3	17 Aug 2000 – 17 Aug 2000 28 Jun 2008 – 30 Jun 2008	3	none
		01 Jan 2010 0:00 – 14 Feb 2012 12:45	0.4	18 Jul 2010 – 18 Jul 2010	1	none
12413470	SF – Pinehurst	12 Aug 1987 13:45 – 31 Dec 1989 23:45	19	2 Nov 1988 – 21 Nov 1988 4 Feb 1989 – 19 Mar 1989 26 Mar 1989 – 26 Mar 1989 24 Apr 1989 – 15 Jun 1989 8 Aug 1989 – 15 Aug 1989	53	none
		01 Jan 1990 0:00 – 31 Dec 1999 23:45	5.9	20 May 1993 – 29 Sep 1993 11 Jan 1995 – 21 Feb 1995 10 Dec 1995 – 11 Dec 1995 23 Jan 1996 – 4 Feb 1996	133	none
		01 Jan 2000 0:00 – 31 Dec 2009 23:45	0.9	27 Jan 2000 – 27 Jan 2000 6 Oct 2000 – 9 Oct 2000 3 Jun 2001 – 4 Jun 2001 18 Oct 2001 – 18 Oct 2001 4 Jan 2004 – 5 Jan 2004 28 Apr 2008 – 28 Apr 2008	4	none
		01 Jan 2010 0:00 – 14 Feb 2012 13:00	0.02	None	N/A	none
12413500	CDR - Cataldo	30 Sep 1986 23:15 – 31 Dec 1989 23:45	3.2	26 Nov 1986 – 22 Dec 1986 28 Mar 1989 – 30 Mar 1989	27	none
		01 Jan 1990 0:00 – 31 Dec	19	29 Apr 1991 – 7 May 1991 19 May 1993 – 29 Sep 1994	499	Long missing stretch (499

Gage ID	Name	Time Period	% Missing	Periods Missing Complete Days	Longest Missing Days	Notes
		1999 23:45		12 May 1995 – 21 May 1995 14 Dec 1996 – 2 Feb 1997 5 Dec 1997 – 5 Dec 1997 10 Jan 1998 – 13 Jan 1998		days)
		01 Jan 2000 0:00 – 31 Dec 2009 23:45	0.3	8 Aug 2006 – 8 Aug 2006	1	None
		01 Jan 2010 0:00 – 14 Feb 2012 10:30	1.6	None	N/A	High percent missing for not having any continuous missing days
12413860	CDR – Harrison	01 Mar 2004 0:00 – 14 Feb 2012 10:15	14	29 Oct 2004 – 7 Nov 2004 25 Nov 2005 – 27 Nov 2005 03 May 2007 – 03 May 2007 29 Jun 2007 – 3 Sep 2007 5 Feb 2008 – 07 Feb 2008 9 Jul 2008 – 2 Nov 2008 21 Dec 2008 – 06 Jan 2009 23 Jan 2009 – 26 Jan 2009 18 May 2009 – 31 May 2009 06 Jun 2009 – 07 Jun 2009 10 Oct 2009 – 13 Oct 2009 21 Nov 2009 – 19 Jan 2010 19 Jan 2011 – 03 Mar 2011 18 Dec 2011 – 38 Dec 2011 10 Jan 2012 – 29 Jan 2012	117	*Some negative values in data set; changed to value of '1' in DSS *Last two missing ranges not filled with average daily flow (ave daily flow not available)

Gage Height Data Notes

The following table summarizes the data sets (missing values, period of record, special notes, etc.)

Gage ID	Name	Time Period	% Missing	Periods Missing Complete Days	Longest Missing Days	Notes
12413500	CDR - Cataldo	01 Oct 1986 0:15 – 14 Feb 2012 10:30	21.3	26 Nov 1986 – 22 Dec 1986 28 Mar 1989 – 30 Mar 1989 29 Apr 1991 – 7 May 1991 19 May 1993 – 30 Sep 1994 12 May 1995 – 22 May 1995 14 Dec 1996 – 02 Feb 1997 05 Dec 1997 – 05 Dec 1997 10 Jan 1998 – 13 Jan 1998 02 Jan 2001 – 30 Sep 2002 03 Oct 2002 – 31 May 2004 03 Jul 2004 – 30 Sep 2004 08 Aug 2006 – 08 Aug 2006	637	Several long missing stretches (500, 607, 637 days)

Gage ID	Name	Time Period	% Missing	Periods Missing Complete Days	Longest Missing Days	Notes
12413860	CDR – Harrison	01 Mar 2004 0:00 – 14 Feb 2012 10:15	14	29 Oct 2004 – 7 Nov 2004 25 Nov 2005 – 27 Nov 2005 06 Feb 2008 – 07 Feb 2008 06 Aug 2008 – 10 Aug 2008 23 Jan 2009 – 26 Jan 2009 18 May 2009 – 19 May 2009 29 May 2009 – 31 May 2009 06 Jun 2009 – 07 Jun 2009 10 Oct 2009 – 13 Oct 2009 21 Nov 2009 – 23 Nov 2009	10	

Attachment C
Electronic Files of HEC-RAS Model, including Boundary Conditions and Level Logger Data

ES013111145949PD